SCIENTIFIC ABSTRACTS AND SESSIONS

SUNDAY, JULY 30

Educational Symposium Valencia A
Education Council: AAPM History/Public Education

SU-AA-ValA-01
Reflections of the Founding of the AAPM
R Gould*, University California San Francisco, San Francisco, CA

(No abstract provided)

SU-AA-ValA-02
Getting Medical Physicists On Local TV News: The Discoveries & Breakthroughs Program
B Stein*, AIP, College Park, MD

Discoveries & Breakthroughs: Inside Science (DBIS) is a nationally syndicated television program, consisting of a dozen 90-second news segments per month, produced by the American Institute of Physics in conjunction with partner societies including AAPM. Marketed and distributed to local television stations across the country, DBIS provides a unique opportunity to present science and scientists to local TV news viewers, who represent an important yet underserved segment of the US public for science news. This presentation will show some DBIS news clips on medical physics and explain the stories behind them. It will present quantitative studies, funded by NSF, which have demonstrated the effectiveness of the program. It will show a new website, especially created for AAPM members, that contains dozens of medical-physics-related DBIS videos which may be useful for outreach and other purposes. This talk will also explore how to increase opportunities for maximizing coverage of medical physics by the program.

Educational Objectives:
1. Understand the format of the *Discoveries & Breakthroughs* television program, its objectives, and the importance of its target audience.
2. Learn the complete process of how DBIS segments on medical physics are created from story idea to final production.
3. Understand how to submit story ideas for the program, serve as an outside expert for stories under consideration, and generally help DBIS maximize its coverage of medical physics.

Professional Symposium Valencia B
Professional Council Symposium: Ethics and Conflict of Interest in Publishing, Research and Patient Care

SU-BB-ValB-01
Authorship, Competing Interests, and the Responsible Conduct of Research"
F Macrina*, Vice President for Research, Virginia Commonwealth University, Richmond, VA

(No abstract provided)

SU-BB-ValB-02
Ethical Conflicts in the Clinical Workplace
D. Jay Freedman, Chair, AAPM Ethics Committee

(No abstract provided)

Joint Imaging/Therapy Symposium Valencia A
Young Investigators Symposium

SU-CC-ValA-01
Automatic Comparison Between Reference and On Board Digital Tomosynthesis for Target Localization
L Ren*, D Godfrey, J Wu, H Yan, F Yin, Duke University, Durham, NC, Duke University Medical Center, Durham, NC

Purpose: Digital tomosynthesis (DTS) is a method for reconstructing 3D images from cone-beam projection data acquired with limited angulation (e.g., 40^o) of an x-ray source, and is much faster and lower dose than full cone-beam CT (CBCT). We previously developed a method for generating reference DTS images from a planning CT for registration with actual on-board DTS images. This study examines the accuracy of 3D-3D registration of reference and on-board DTS images to assess the potential of DTS for image-guided radiation therapy (IGRT). **Method and Materials:** We simulated the online positioning of an anthropomorphic chest phantom with 6 noncoplanar reference BBs attached. Planning CT data of the phantom were acquired with a G.E. Lightspeed RT scanner. On-board CBCT projection data were acquired with a Varian 21EX Clinac, equipped with a kV on-board imager. On-board DTS images were reconstructed from a subset of the CBCT projection data (81 projections, 44^o). True alignment of planning and on-board image data was achieved according to a 3D point-based registration of the 6 reference BBs in the CT and CBCT images. Single-axis rotations up to +/- 10^o and 3-axis translations up to +/- 10 mm were simulated in the planning CT, prior to the generation of reference DTS images. A 67.5mm × 162.5mm × 20.8mm region of interest surrounding the spinal cord was extracted for registration. Mutual information-based 3D-3D registration of reference and on-board DTS images was performed, and residual registration error was recorded. **Results:** Registration errors are within 0.7mm and 0.1 degree in all cases. The average registration error was 30% less for translations along the dimension of tomographic motion than for the other two dimensions. **Conclusions:** 3D-3D rigid-body registration of reference and on-board DTS images is highly accurate, suggesting that DTS may be an effective IGRT technique. **Partially supported by a Varian research grant**.

SU-CC-ValA-02
More Accurate Determinations of Air-Kerma Strength for Brachytherapy Sources
W Culberson*, L DeWerd, University of Wisconsin, Madison, WI

Purpose: To determine more accurately the air-kerma strength of low-energy photon-emitting brachytherapy sources. **Method and Materials:** Air-kerma strength is the agreed upon metric for most brachytherapy sources and is defined as the product of the kerma rate *in vacuo* at distance d on the transverse axis of a seed (polar angle of 90 degrees), multiplied by the square of this distance d^2. This work introduces new methods to evaluate how anisotropy affects air-kerma strength. First, NaI detector measurements yield in-air anisotropy data that were previously reported only with Monte Carlo transport methods. In addition, multiple aperture sizes are used to evaluate large-angle free-air ionization chamber measurements. Lastly, a new method of Monte Carlo transport, which incorporates the distance-dependent geometry effects of certain brachytherapy seeds, is used to determine more accurately the air-kerma rate on the transverse axis of the source. These methods may be used to evaluate air-kerma strength to a higher degree of accuracy. **Results:** Well-collimated NaI detector measurements yield precise in-air anisotropy measurements that may be compared directly with Monte-Carlo transport simulations. Measurements of two seed types show deviations near the transverse axis of the source of at least 5%. Monte-Carlo determined point-detector simulations yield more accurate estimations of air-kerma strength and show that air-kerma strength is not constant for all distances *in vacuo*, as would be predicted by its definition. **Conclusion:** This work shows that with the combination of these new measurement techniques, air-kerma strength may be evaluated to a higher degree of accuracy for low-energy photon-emitting brachytherapy sources. New experimental data on two seeds' in-air anisotropy is also presented.

SU-CC-ValA-03

A Directional Algorithm for An Electronically-Collimated Gamma-Ray Detector for Intraoperative Localization of Radiation Sources

A Lackie*, K Matthews II, B Smith, W Hill, W-H Wang, M Cherry, Louisiana State University, Baton Rouge, LA

Purpose: An electronically-collimated gamma-radiation detector for intraoperative localization of sentinel lymph nodes and metastases is under development. Analogous to Compton telescopes and Compton cameras, localization is achieved using the coincidence detection of Compton-scattered gamma rays. Electronic collimation allows the device to operate without physical collimation, providing high sensitivity while also allowing directional information to be determined. We report on implementation of algorithms to calculate the direction to the source. **Methods and Materials:** Two approaches to direction reconstruction were evaluated. The first technique backprojects each event onto the surface of a sphere centered on the device's primary detector. To use Fourier filtering methods for deblurring, the sphere's surface is mapped by stereographic projection onto a plane, filtered in Fourier space, and then projected back onto the sphere. The second technique also backprojects events onto the sphere, then determines the rectangle that circumscribes the backprojected cone; localization is obtained by intersection of all circumscribed rectangles. **Results:** Performance of the algorithm has been evaluated using randomly generated ideal Compton-scatter events from point sources for our detector geometry. Direction angles are calculated within 5% accuracy for source positions up to 45° off-axis for the filtering approach and ~30° for the circumscription approach. Error in calculated direction angles depends on the arbitrary diameter of the sphere; optimally, the sphere should intersect the source. The circumscription technique converges to an estimate of direction angles in ~50 events; the filtering approach requires ~1000 events. **Conclusion:** The two methods complement each other in speed and field-of-view. Monte Carlo simulations and experimental testing of a prototype system are ongoing as a separate part of the overall project; data from these will further supplement evaluation of the algorithms. **Acknowledgment:** Supported by Homeland Security Advanced Research Projects Agency, and Space and Naval Warfare Systems Center San Diego; Contract No. N66001-05-C-6024

SU-CC-ValA-04

Using Flow Information to Support 3D Vessel Reconstruction From Rotational Angiography

I Waechter*[1], J Bredno[2], J Weese[2], D Hawkes[1], (1) University College London, London, GB, (2) Philips Research Aachen, Aachen, DE

Purpose: For the assessment of cerebral vessel diseases, it is very beneficial to obtain three dimensional morphologic and haemodynamic information about the vessel system. Our goal is to determine both concurrently using one rotational angiography sequence. To enable the extraction of flow information, the rotational angiography images should show inflow and outflow of contrast agent. Images with this property however, are not well suited to standard volume reconstruction algorithms. This work shows how flow information can support the vessel reconstruction to overcome this conflict. **Method and Materials:** In our method flow information is used as follows to determine, for every voxel, the likelihood of being inside a vessel: First, the rotational time intensity curve (R-TIC) is determined from the image intensities at the projection points of the current voxel. Next, the arrival time of the contrast agent bolus at the voxel is estimated from the R-TIC. Finally, a measure of the intensity and duration of the contrast enhancement is determined. The likelihood is used to steer the Fast Marching algorithm, which determines the order in which voxels are analyzed. This enables the centreline of the vessels to be extracted by backtracking. The proposed method was tested on 80 computer simulated rotational angiography sequences with systematically varied blood flow and contrast agent injection parameters. **Results:** The mean error in the 3D centreline and radius estimation was 0.62 mm and 0.28 mm respectively. Pulsatile blood flow was found to increase the error only slightly (0.05 mm). **Conclusion:** Under pulsatile and non-pulsatile conditions, flow information can be used to enable a 3D vessel reconstruction from rotational angiography with inflow and outflow of contrast agent. Future work will aim to extract more quantitative flow information. **Conflict of Interest:** Research sponsored by Philips Research Aachen

SU-CC-ValA-05

Advanced Integral Method for the Simulation of Diagnostic X-Ray Spectra

C Dodge*, M Flynn, Henry Ford Health System, Detroit, MI

Purpose: To create a fast and accurate computer algorithm for simulating the emission x-ray spectra from diagnostic tubes as a function of tube voltages, target material, and take-off angles. **Method and Materials:** The method uses an integral model to determine the radiative losses from an electron as it slows down in arbitrary media. The effect of self-absorption and backscatter is accurately described by distribution functions for electron number, electron depth, and angular distribution that are functions of electron slowing down energy. The Monte Carlo program PENELOPE was used to determine these three distribution functions. An exact accounting of electron orientation was found necessary due to large variations in the Bremsstrahlung cross-section as a function of emission angle. These are accounted for in the integral model by pre-computing tables based on the Kissel Bremsstrahlung shape function. Characteristic x-ray emissions as a function of over-voltage are described using Monte Carlo results for both direct and indirect production. The computer algorithm is implemented as a part of a larger program for computationally simulating x-ray production, transmission, scattering, and detection for imaging systems (XSPECT, V4.0). **Results:** We compared our program to the measured x-ray spectra of Mercier, and spectral computations of PENELOPE. We found good agreement and an improvement over prior semi-empirical estimates (Birch & Marshall, Tucker, Storm). **Conclusion:** We have developed a program that can simulate x-ray spectra from tubes of arbitrary anode materials (including alloys), and target angles for tube voltages of 1 to 400 kV. After generation of target specific tables, the x-ray spectra can be computed in a few seconds. The results are equivalent to Monte Carlo estimates that require days to compute a single spectra.

SU-CC-ValA-06

A Novel Approach to Assessing Breast Density Utilizing Sound Speed Measurements

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Purpose: Women with high mammographic breast density are at a 4- to 7-fold increased risk of developing breast cancer compared to women with fatty breasts. The purpose of this work is to investigate the potential of assessing breast density via acoustic velocity measurements obtained with ultrasound computed tomography. **Method and Materials:** A sample of approximately 50 patients was imaged with our computed ultrasound tomography clinical prototype. Each data set was comprised of 45 tomograms ranging from near the chest wall through the nipple region. Whole breast acoustic velocity was determined by creating image stacks and evaluating the sound speed frequency distribution. The acoustic measures of breast density were evaluated by comparing these results to two mammographic density measures: (1) qualitative, as determined by a certified radiologist using the BIRADS Categorical Assessment based on a 1 (fatty) to 4 (dense) scale, and (2) quantitative, via digitization and computerized analysis of archival mammograms. The former involved a radiologist's visual assessment of each mammogram, while the latter required scanning cranio-caudal films with a Vidar VXR-16 DosimetryPro digitizer and implementing semi-automatic segmentation routines. **Results:** Approximately 60 m/s difference in acoustic velocity was found between the fatty and dense BIRADS categories. This investigation indicated a positive correlation between BIRADS category and acoustic velocity of the breast. In addition, a strong correlation between the mean acoustic velocity and quantitative measures of percent breast density was demonstrated (Pearson correlation coefficient 0.651, $p < 0.001$). **Conclusion:** These results support the hypothesis that utilizing acoustical velocity as an analogue to mammographic breast density is feasible. Our approach to evaluating breast density has the potential to provide a safer, non-ionizing, and more quantitative means of evaluating breast density, thus better elucidating the relationship that exists between breast density and breast cancer risk.

SU-CC-ValA-07

Air Kerma Rate Measurements From a Miniature X-Ray Source Using Free-Air Ionization Chambers

S Davis*[1], J Micka[1], L DeWerd[1], T Rusch[2], (1) University of Wisconsin, Madison, WI, (2) Xoft, Inc, Fremont, CA

Purpose: To measure the air kerma rate from a miniature x-ray source using free-air ionization chambers (FACs), and to transfer the source air kerma rate to a well-type ionization chamber. **Method and Materials:** Air kerma rates from several Xoft AXXENT™ miniature x-ray sources were measured in air along their transverse axes using three different FACs, each with a source-to-aperture distance of 100 cm. The sources were operated at 50 kV and 100 μA beam current. The University of Wisconsin (UW) Attix FAC was used for the initial measurements, and follow-up measurements were performed using the Attix and Ritz FACs at the National Institute of Standards and Technology (NIST). Two different FAC aperture sizes were used for each of the air kerma rate measurements at NIST. Additional measurements for each source were performed using a well-type ionization chamber with a custom-built aluminum source holder. The ratio of air kerma rate at 100 cm to well chamber current was used to determine a well chamber calibration coefficient for each source. **Results:** The air kerma rates for the smaller aperture were generally within 2% of the rates measured with the larger aperture, indicating that the sources were aligned properly. The well chamber calibration coefficients demonstrated some source to source variation, with an overall standard deviation of 5.3%. The results suggest that most of this variation can be attributed to azimuthal anisotropy around the long axes of the sources, and not differences in the photon spectrum emitted from each source. **Conclusion:** Both the Attix and Ritz FACs are appropriate for measuring air kerma rates from the miniature x-ray sources, but further work will be necessary to develop methods suitable for traceability to national measurements standards. **Conflict of Interest:** Funding for this research was provided by Xoft, Inc.

SU-CC-ValA-08

Air-Kerma Strength Determination of a 169Ytterbium High Dose Rate Brachytherapy Source

J VanDamme*, L DeWerd, J Micka, W Culberson, S Davis, University of Wisconsin Medical Radiation Research Center

Purpose: To provide an accurate determination of the new ^{169}Yb high dose rate (HDR) bracytherapy source in terms of air kerma strength, based on an adaptation of the current, NIST traceable, in air measurement standard in use for ^{192}Ir HDR sources. **Methods and Materials:** Several modifications to the seven distance technique, which is the current standard for HDR source strength measurement, were required to adapt it to the ^{169}Yb spectrum. An Exradin A4 spherical chamber was employed, which has a relatively flat chamber response to the range of energies in the ^{169}Yb spectrum, and has been verified to accurately measure the air kerma strength of ^{192}Ir to within the reported uncertainty of the current standard measurement technique. To convert the electrometer readings to source strength, a chamber coefficient, N_k, was determined by using the NIST calibrated chamber coefficients from several NIST H-Beams, whose energy spectrums fall strategically within the ^{169}Yb spectrum. Several correction factors must be applied to these electrometer readings, including corrections for temperature and pressure, air attenuation, air scatter, ion recombination, and corrections for the finite size of the chamber. **Results:** The decay corrected average of fourteen measurement iterations was 8.063 x 10^{-3} Gy-m^2/hr. Analysis of uncertainty was performed on these experimental ^{169}Yb air kerma measurements using the standard NIST method for evaluating uncertainty. This analysis established an overall k = 2 expanded uncertainty of 2.10%. **Conclusion:** It is shown that, with a few modifications, the current standard for high dose rate brachytherapy source calibration could be employed to accurately calibrate the new ^{169}Yb HDR brachytherapy source in terms of air kerma strength. The uncertainties as analyzed fall within those currently used for ^{192}Ir calibration. **Conflict of Interest:** Research funding provided by Implant Sciences Corporation.

SU-CC-ValA-09

Radiation Quality in High Contrast Imaging with Orthogonal Bremsstrahlung Beams

A Sarfehnia*, K Jabbari, J Seuntjens, E Podgorsak, McGill University, Montreal, Quebec

Purpose: To study the characteristics of orthogonal bremsstrahlung photons produced by megavoltage electron pencil beams and to evaluate the suitability of their use for improved radiation therapy imaging. **Method and Materials:** A 10 MeV electron beam emerging through the research port of a Varian Clinac-18 linac was made to strike targets of carbon, aluminum and copper. The quality of resulting forward and orthogonal bremsstrahlung beams was evaluated using PDD and attenuation measurements, and the experimental findings were compared with Monte Carlo-calculated results using the EGSnrcMP code. Images of contrast objects were acquired with Agfa 400 diagnostic films and their contrast levels were analyzed. **Results:** Photon yield and mean energy of the forward bremsstrahlung spectra were determined to be essentially independent of the target's atomic number Z. In comparison with forward bremsstrahlung, the yield and effective energy were lower in the orthogonal direction, and this decrease was more pronounced for targets of lower atomic number. The effective energy of a spectrum produced by carbon dropped by a factor of 10 from 1535 keV in the forward direction to 151 keV in the orthogonal direction, while for aluminum it dropped by 77% to 425 keV, and for copper by 37% to 1107 keV. The image contrast of films exposed with orthogonal beams was qualitatively determined to be superior to that obtained using the forward megavoltage beams. **Conclusions:** Orthogonal bremsstrahlung beams produced by megavoltage electrons have a significantly lower mean energy compared to forward beams. In the orthogonal direction, higher Z targets create higher intensity, while lower Z targets provide a more desirable low energy spectrum. Using their relatively low effective energy, orthogonal bremsstrahlung beams produced by megavoltage electrons striking low atomic number targets yield images with a higher contrast than do forward bremsstrahlung beams.

SU-CC-ValA-10

Cone-Beam CT for Radiation Therapy with Reverse Helical Trajectory

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Purpose: To propose and study a novel scanning trajectory, named reverse helical trajectory, for a cone-beam CT (CBCT) imager mounted on a linear accelerator (LINAC) treatment system by applying an exact 3D backprojection filtration (BPF) algorithm. **Method and Materials:** A numerical study using 3D Shepp-Logan phantom was performed. We applied the PI-line-based BPF algorithm to reconstruct exact 3D image from data acquired numerically for a reverse helical trajectory. It was revealed that there is a middle gap in the reconstructed image which is due to lack of PI-lines passing through the gap. Application of a chord-based BPF algorithm showed a reduction in the middle gap. Two kinds of line plus reverse helical trajectories were proposed and tested to reduce the middle gap further. One of them is a reverse helical trajectory with a short line segment between two helices separated apart. The other one is a reverse helical trajectory with a long line segment connecting the end points of the revere helices. **Results:** The middle gap in the reconstructed image was reduced by employing a chord-based BPF algorithm. The gap was reduced further when we modified the scanning trajectory by inserting a line segment between two helices. The gap was removed completely when we used a reverse helical trajectory with a long line segment connecting the end points of the revere helices. **Conclusion:** A novel scanning geometry for a LINAC-mounted CBCT imager was proposed, and a preliminary numerical study was performed. The middle gap in the reconstructed image obtained by PI-line-based BPF algorithm was effectively eliminated by using a chord-based BPF algorithm with a line plus reverse helical trajectory.

Exhibit Hall F

Therapy Moderated Poster Session

Moderated Poster - Area 1 (Therapy): IMRT Planning and Dosimetry

SU-DD-A1-01

Advances in Co-60 Based Tomotherapy Including Megavoltage CT

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Purpose: To evaluate the potential for Co-60 based tomotherapy including dose delivery and mega-voltage CT (MVCT). Tomotherapy is a rotational implementation of IMRT that provides highly conformal doses and patient setup verification using MVCT. Current tomotherapy is limited to linear accelerators. This poster presents advances in our investigation of Cobalt-60 based tomotherapy, including MVCT. **Method and Materials:**

The fundamental components for the Co-60 tomotherapy dose delivery and MVCT imaging experiments are a benchtop motion stage and a clinical Co-60 MDS Nordion T-780 unit. Film and polymer-gel dosimetry are used to validate the tomotherapy dose delivery planned using in-house software. Imaging is provided by a Varian Portal Vision LC250 EPID. MVCT imaging is demonstrated using a variety of phantoms, including an anthropomorphic head phantom, and various contrast phantoms. EGS Monte Carlo simulation is used to model different beam delivery approaches such as source design for increased radiation output. **Results:** The computer simulations, film dose measurements, and three-dimensional polymer gel dosimetry all demonstrate that Co-60 tomotherapy provides conformal dose delivery required of modern IMRT techniques. Film measurements show that dose delivery corresponds excellently with treatment plans, validating our in-house planning system. Treatment planning studies show that Co-60 tomotherapy delivery compares favourably with that from linac based 6MV tomotherapy. Dose volume histograms show identical coverage and avoidance of target critical organs. Imaging results show that Co-60 CT provides sufficient contrast and resolution for image guidance. Results from Monte Carlo studies show that it is possible to increase beam output for a dedicated Co-60 tomotherapy unit by modifying the source geometry. **Conclusion:** Co-60 is well suited to tomotherapy and imaging applications; the development of clinical implementations of Co-60 tomotherapy is warranted and work continues in our centre along these lines.

SU-DD-A1-02

Variations of Energy Spectra and Water-To-Material Stopping-Power Ratios in Three-Dimensional Conformal and IMRT Photon Fields

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Purpose: Complex dose distributions and dose gradients in IMRT may cause spatial variations in photon- and electron-energy spectra. This study examined the change of photon- and electron-energy spectra, and their effects on dosimeter response and water-to-material stopping power ratios (SPR) for 3D and IMRT beams. The later term is an important factor for dosimetry protocols and obtaining dose-to-water conversion in Monte Carlo dose calculations. **Method and Materials:** The Monte-Carlo BEAM-EGSnrc system was used to simulate external-beam photon fields with 3D or IMRT features. Electron and photon energy fluences and spectra were calculated on a voxel-by-voxel basis using track-length estimation for 3D and IMRT treatment plans. The water-to-material SPR were averaged over the voxel of interest with the electron spectra using the Spencer-Attix theory. The relative response of ion chambers, films, and TLDs were modeled using the photon and electron spectra. **Results:** There was a strong spatial dependence of photon-energy spectra in both the 3D and IMRT fields. The low-energy (<100 keV) component of the photon spectra increased inversely with doses because of the contribution of the scattered photons. A similar effect was observed for electrons but to a much smaller extent. As a result, the response of film could increase by more than 10% in the low-dose region, whiles the changes of ion chamber and TLD response were within 3%. On the other hand, the variation of the water-to-material SPR with energy spectra and spatial locations was not clinical significant (< 1%) for soft tissue, cortical bone, and lung, and was less than 2% for dry air. **Conclusion:** Photon- and electron-spectra are spatial- and dose-dependent in 3D and IMRT photon fields. The spectra variation should be considered for certain dosimeters whose responses are energy dependent. For patient-like materials, the water-to-material SPR was relative stable in spite of the spectral variation.

SU-DD-A1-03

IMRT Quality Assurance: Dosimetric Assessment of Three Current Methods

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Purpose: To compare traditional IMRT quality assurance using film dosimetry and small volume ionization chamber measurements with two new commercial products, the Wellhofer® MatriXX ionization chamber array and Varian® Portal Dosimetry. Available analysis software, hardware requirements and approximate operator times for data preparation, measurement and analysis will also be examined. **Method and Materials:** Fluence patterns from several 6X and 18X IMRT treatment plans for pelvis and head and neck radiotherapy patients were measured using radiographic film, the MatriXX array, and the Portal Dosimetry array. In each case the fluence pattern predicted by the treatment planning system was compared to the measured fluence pattern using ordinary γ-analysis. Absolute dose at a point in a low-gradient region of the fluence was also measured in the solid water phantom with an ionization chamber and compared to the dose prediction of the TPS. The absolute dose measured at the same point by the MatriXX array was also compared. **Results:** The absolute dose measurements made in a region of low-gradient using an ionization chamber were, on the average, within 3% of the TPS predicted dose. The absolute dose measurements made using the MatriXX were, on the average, within 5% of the predicted dose. The ion chamber and MatriXX agreed to within 3%. An average of about 4% of pixels failed an ordinary γ-analysis using 5% dose agreement and 3mm DTA criteria for both film and MatriXX measurements. A smaller percentage of pixels measured using Portal Dosimetry failed. The time spent preparing the data was comparable for all methods. Data measurement and analysis times were significantly reduced using the MatriXX and Portal Dosimeter procedures. **Conclusions:** This work indicates significant time savings for the new methods. In addition, the MatriXX system measures absolute dose at each chamber position.

SU-DD-A1-04

In Vivo Prostate IMRT Dosimetry With MOSFET Detectors Using Brass Build-Up Caps

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Purpose: To develop a general formalism with various correction factors to predict dmax entrance dose with the new hemispherical brass buildup caps to be used with MOSFET detectors in anterior prostate IMRT fields and thereby integrate in vivo IMRT dose measurement as part of routine QA process in IMRT radiotherapy **Method and Materials:** We have used the new wide energy hemispherical build-up caps for this study. Due to its high density and high atomic number it provides the minimal amount of metal needed to achieve full build-up at Dmax for a range of photon energies. We have developed a general formalism to predict Dmax entrance dose by applying necessary correction factors after studying the response of MOSFET with brass build up caps for energy, dose rate, dose reproducibility, SSD and patient specific IMRT correction factor. **Results:** In vivo Prostate IMRT dose measurements with MOSFET detectors using brass buildup caps was performed and compared against dose predicted by two different treatment planning systems. We used both 6 MV and 10 MV for this study and compared the in vivo MOSFET detector reading with dose predicted by Philips Pinnacle (6 MV) and CMS XiO (10 MV) treatment planning systems respectively. We achieved a overall accuracy of better than ± 5% on measured patient doses. **Conclusion:** Routine IMRT QA in most institutions today only involves verifying the optimized fluence map delivered to the patient in a test phantom at a certain preset depth. Based on our work here, we believe adding in vivo IMRT dosimetry with MOSFET detectors using the new brass build up caps along with routine fluence map verification in phantoms and MLC quality assurance offers greater accuracy and confidence in actual dose delivered to the patient.

SU-DD-A1-05

A Ray Tracing Method to Generate Initial Conditions for IMAT Optimization

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Purpose: To investigate the utility of using ray tracing to extract intrinsic information from CT, contour and primary dose data in order to determine initial conditions (number of arcs, arc weights, arc ranges and leaf positions) that can be input into an Intensity Modulated Arc Therapy (IMAT) optimization routine. Methods and Materials: Patient CT and contour data was ray-traced to determine PTV and PTV-OAR arcs. An additional arc was determined by the calculation of a ray importance factor (RIF) through ray tracing of the primary dose ray-tracing of the PTV. All three sets of arcs were then input into a previously described leaf position optimization algorithm. This method was tested on two geometries by ray tracing 27 equi-spaced beams. The optimized arc deliveries (number of arcs, arc weights, arc ranges and leaf positions) were then input into a fast

dose calculation algorithm, NXEGS (NumeriX LLC) for dose calculation and comparison with primary dose as calculated by ray tracing. **Results:** RIF arc addition reduced the objective function by 20% for geometry 1 and 8% for geometry 2. Leaf position optimization further reduced the objective function by 27% for geometry 1 and 29% for geometry 2. Calculation of dose using NXEGS provides accurate dose distributions for IMAT. **Conclusions:** Ray tracing can quickly provide information about number of arcs, arc ranges, arc weights and leaf positions with very little user input. Leaf position optimization can improve leaf positions once the initial number of arcs and arc ranges are determined. Together these two steps can produce intensity modulated arcs for further optimization with a more accurate dose calculation algorithm.

SU-DD-A1-06

Prostate IMRT Dose Escalation with Urethra Sparing: Dose Painting with IGRT

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Purpose: With IGRT, the geometric uncertainty in treatment can be reduced, which makes it feasible to implement IMRT dose painting with a reasonable resolution. In this cancer center, an on-line realignment protocol is utilized for prostate cancer patients. This IGRT protocol is based on use of implanted gold fiducial markers and EPI. In this study, dose escalations with urethra sparing have been tested by using IMRT dose painting. **Method and Materials:** CT scans of three patients were chosen from the IGRT group. The original 3D-CRT plan (74Gy/37fr, 10mm PTV margin) was used as a reference. In test IMRT plans two PTVs were generated. PTV1 was defined as 5mm extension of prostate. PTV2 was generated from PTV1 with 5mm margin subtracted for bladder, rectum, and urethra. Two raw plans were generated. Plan 1 was 74Gy/37fr to PTV1, and Plan 2 was 74Gy/37fr to PTV2. Then, the urethra sparing IMRT boost plan was generated as a weighted sum of the two raw plans, e.g. Real Plan=w_1×Plan1+ w_2×Plan2. Different combinations of weighting factors were tested: $w_1 \in [0.6, 1]$, $w_2 \in [0.1, 0.5]$. The dose to each organ was calculated with organ motion simulated based on actually recorded EPI image mismatches. The tumor control probability (TCP) and effective dose were used to evaluate the plans. **Results:** To achieve the same urethra D50 (minimum dose to 50% volume) as the reference plan, the highest weighting combination was w_1=0.7, w_2=0.5 (Prescription Dose= (0.7+0.5) ×74Gy=88.8Gy). This yields significant dose reduction in bladder and rectum. For the considered patient the TCP increases from ~74% to ~95%. **Conclusion:** With IGRT, the urethra sparing IMRT dose painting is superior to the 3D-CRT plan. The total prescription dose can be as high as 88Gy, with TCP of ~95% and lower GI complication. Since urethra has been spared, the GU complication will be less.

Exhibit Hall F

Joint Imaging/Therapy Moderated Poster Session

Moderated Poster - Area 2 (Joint): Modeling of Intra-Fraction Organ Motion

SU-DD-A2-01

On the Accuracy of a Moving Average Algorithm for Tracking Respiratory Motion During Radiation Therapy Treatment Delivery

R George*[1], J Williamson[1], M Murphy[1], E Weiss[2], P Keall[1], (1)Virginia commonwealth University, Richmond, VA, Virginia Commonwealth University, Richmond, VA, (2) Georg-August-Universität, Göttingen, DE

Introduction: Real-time motion tracking (RTT) treatment delivery has several advantages toward the improvement of accuracy for radiotherapy. However, currently there are certain limitations to this technique. The purpose of this study was to investigate an alternative treatment scenario using a moving average algorithm (MA) for treatment which could potentially be approaching the accuracy of RTT. **Method:** A comparison was performed between three different treatment scenarios

(1)RTT: $X_{est}(t) = X_{act}(t - RT)$;

(2)MA: $X_{est}(t) = mean[X_{act}(t - RT) : X_{act}(t - RT - n)]$;

(3)Static beam delivery (SB) $X_{est}(t) = mean[X_{act}(0) : X_{act}(n)]$

Where $X_{est}(t)$ and $X_{act}(t)$ are the estimated and actual position at time t, n in seconds is the averaging period (5-25 seconds range). The data used for this analysis was 331 respiration-motion traces from 24 lung-cancer patients acquired using three different breathing types (free breathing(FB), audio coaching(A) and audio-visual biofeedback(AV)). The metrics used for comparison were the group systematic error(M), the standard deviation(SD) of the systematic error(Σ), and the root mean square of the random error(σ). The averaging period was varied to study the effect on the various metrics. Margins were calculated using the formula by Stroom *et al*. *(IJROBP 1999;43(4))* **Results:** M and Σ are negligible for both MA[$M \in (-0.01,0), \Sigma \in (0,0.01)$] and RTT[$M \in (0), \Sigma \in (0)$] compared to SB[$M \in (-0.15,-0.02), \Sigma \in (0.05\text{-}0.20)$]. MA(0.48-0.54) has a slightly reduced σ than SB(0.53-0.57). Negligible improvements were found by varying the average periods for M and Σ. σ was found to be insensitive to the different averaging periods(0.53-0.56 for A). From the margin calculations FB is most affected by the different treatment scenarios. (All values in cm). **Conclusions:** MA has accuracy advantages over SB and practical advantages over RTT. MA significantly reduces M and Σ compared with SB. MA and SB require less margins for AV than that for FB and A. The margins required for RTT are independent of breathing training type. There is a group systematic error caused by intrafraction motion during FB.

SU-DD-A2-02

Variability of Waveforms and Probability Distributions in External Respiratory-Surrogate Marker Data

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Purpose: To investigate intra- and inter-fractional, inter-subject variability in the motion patterns of external respiratory-surrogate markers. A strong correlation between the motion of external markers and internal targets has been previously reported. **Method and Materials:** Varian real-time position management (RPM) system is used clinically to monitor external marker motion. We analyzed over 450 RPM datasets (traces) from 186 4D-CT, and 6 gated radiotherapy subjects (mean length: 235 seconds). Aperiodic (long-term) motion components were subtracted by applying high-pass filtering to Fourier transform of the data. Probability distribution functions (PDF) of the marker position were constructed, and variability bounds were calculated for the realized distributions. Trace-average waveforms (TAW) were constructed from cumulative PDF, calculated separately for leading and trailing edges of motion cycles within the trace. **Results:** Inter- and intra-fractional variability of PDF were reduced where the aperiodic motion components were subtracted from the data. The distribution of aperiodic shifts was approximately Gaussian over multiple fractions. Comparison between the data from various subjects showed that the PDF (when normalized to the mean amplitude of individual traces) was remarkably stable, indicating rather limited inter-fractional and inter-subject variability. While intra-fractional variability of PDF appeared to be typically larger than either inter-fraction or inter-subject, as a wide variety of waveforms were realized within each trace. **Conclusion:** The marker position PDF and its variability bounds, constructed based on a single trace (e.g., pre-treatment 4D-CT), may serve as a conservative estimate of the expected variability in the PDF realized during a fractionated treatment. This information can be used in robust optimization of treatment planning for moving targets. The TAW may potentially be useful in subject classification by "respiratory personality", and prediction of the realized PDF for a given expected uncertainty in the trace extrema positions (full exhale and inhale). **Supported in part by the NCI grant 5P01-CA21239-25**

SU-DD-A2-03

Assessment of Four-Dimensional CT Image Acquisition Quality

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The purpose of the present work is to develop and validate a series of tests to assess the quality of four-dimensional (4D) computed tomography (CT) imaging as applied to radiation treatment planning. Using a commercial motion phantom and two programmable moving platforms with a CT phantom, we acquired 4D CT datasets on two commercial multislice helical CT scanners using different approaches to 4D CT image reconstruction.

4D CT image data sets were obtained as the platform moves in different patterns designed to simulate various breathing patterns. Known inserts were contoured and statistics were generated to evaluate properties important to radiation therapy, namely phase-binning accuracy, geometric accuracy, volume accuracy, and CT number accuracy. Phase-binning accuracy varied by as much as 5% for a 4D procedure in which images were reconstructed, then binned, but exhibited no variation for a 4D procedure in which projections were binned prior to reconstruction. Geometric distortion was found to be small as was volume error. Partial volume effects in the direction perpendicular to the axial planes of reconstruction affected volume accuracy, however. CT numbers were reproduced accurately, but 4D images exhibited significantly more noise than static CT images. Characterization of such properties can be used to better understand and optimize the various parameters that affect 4D CT image acquisition.

SU-DD-A2-04

A Simple Method to Reconstruct a Representative Mid-Ventilation CT Scan From 4D Respiration Correlated CT Scans for Radiotherapy Treatment Planning of Lung Cancer Patients

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Purpose: Four-dimensional (4D) imaging techniques can be used to obtain (respiration) artifact-free CT images of the thorax. However, its use in radiotherapy is limited since clinical treatment planning systems are currently not able to use the full 4D data. The purpose of this study was to reconstruct a representative single 3D CT scan from the 4D data set (with tumor closest to the mean position) for use in radiotherapy planning of lung tumors to enable reduction of treatment error margins. **Method and Materials:** After acquisition of the 4D CT scan (10 frames), the tumor is manually segmented (roughly) in the first frame and automatically (gray-value) registered to the tumor in the subsequent frames. This gives the motion of the tumor during the respiratory cycle in 3D. Subsequently, from the cranio-caudal (CC) tumor motion curve, the mean tumor position and its corresponding mid-ventilation (MV) time-percentage are calculated. The CT scan for planning is reconstructed at this time-percentage. As indication of the merit of this concept, its effect on margins from CTV to PTV and on the PTV volume was calculated covering respiratory motion, respiratory baseline variation and setup errors (systematic and random). **Results:** Based on 13 patients, the worst tumor position accuracy (with respect to the mean tumor position) in the mid-ventilation CT scan occurred in the anterior-posterior direction: -0.7±0.8 mm (due to hysteresis). For these patients, the errors in conventional free-breathing CT were estimated to be 0±3.4 mm (CC) and 0±1.4 mm (AP). The mid-ventilation concept resulted in margin reduction up to 45% and a PTV volume reduction up to 35%. **Conclusion:** The mid-ventilation concept, based on tumor motion, is a simple method to obtain an artifact-free CT scan with smaller systematic errors compared to conventional CT scans. Significant reduction of the PTV volume can be achieved.

SU-DD-A2-05

Impact of Fiducial Marker Placement for the Purpose of Phase Definition of the Respiratory Cycle for 4D-CT Image Reconstruction

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Purpose: Most 4D-CT acquisition methods rely on an externally measurable quantity proportional to the breathing cycle (e.g. chest wall excursion), for 4D-CT image reconstruction. Typically, the position of a single reflective marker placed on the patient's chest is monitored. The marker location is often chosen primarily to maximize the measurable motion irrespective of proximity to tumor location. We examine the behavior of motion of multiple markers, at different locations, placed on the patient surface during 4D-CT acquisition and evaluate the impact of marker location on respiratory cycle phase definition for 4D-CT reconstruction and its subsequent application to radiotherapy planning.**Method and Materials:** An infrared guided positioning system (iGPS), capable of tracking multiple reflective fiducials in 3 dimensions, has been adapted to provide respiratory phase information for 4D-CT reconstruction. Data for 3-5 marker positions, placed at different locations on the patients chest, from 10 patients receiving 4D-CT was examined. **Results:** For most patients (9/10) motion of 3-5 markers is reasonably well synchronized suggesting no significant effect of the fiducial location. For one patient, we observed a marker on the abdomen switch from being completely in-phase to being completely out of phase relative to a marker on the center of the chest. This dramatically illustrates that the phase of a specific external marker may not correspond to the motion, external or internal, near the volume of interest. **Conclusions:** The position of a fiducial marker may affect not only the amplitude of motion but also the observed phase for some patients. The importance of this phase shift depends on how the resulting 4D-CT is ultimately applied to radiotherapy planning. In particular, if specific phases (e.g. extremes) are selected for radiotherapy target definition, special attention should be paid to the location of the fiducial marker and its role in image reconstruction.

SU-DD-A2-06

The Effect of Respiratory Rate and Radiation Timing On Dose Coverage in Dynamic Breast IMRT

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Purpose: IMRT has been shown to be capable of delivering plans with desirable homogeneous dose distribution for breast cancer treatment. However, the dose distribution may be influenced by interplay between dynamic MLC and respiratory motion. The purpose of this study was to investigate the impact of respiratory rate and radiation timing on the dose distribution of breast dynamic IMRT. **Method and Materials:** Using similar setup configuration, a helical CT and 4DCT image sets for six breast cancer patients were collected and contoured. Dynamic IMRT plans were designed using the helical CT images. The planned MLC sequence was segmented according to the respiratory phases with a series of respiratory rates (7.5-30/min) and radiation timing (evenly distributed in respiratory cycles). The segmented dynamic MLC sequences were applied to the radiation fields on the corresponding 4DCT phases. A program was developed to calculate the cumulative dose distribution from all the phases. **Results:** For normal breathing rates (15-20/min), the dose coverage didn't change significantly regardless of radiation starting time. The change of target V_{90} was less than 2%. However, for extremely slow respiratory rates (7.5-10/min), the dose distribution and V_{90} changed significantly depending on the radiation timing. The change of target V_{90} was more than 10%. There was no significant dose coverage change for the underlying heart regardless respiratory rate or radiation timing. **Conclusions:** For breast patients treated with dynamic IMRT, if the respiratory rate of the patient is within the "normal" range then the impact of such respiration on dose coverage of the target was found to be statistically insignificant. However, the dose distribution may change significantly when patient has a slow breathing rate. Respiratory gating may be required to obtain satisfactory dose coverage for such cases. There was no significant dose distribution change for heart regardless respiratory rate or radiation timing.

Exhibit Hall F

Joint Imaging/Therapy
Moderated Poster Session
Moderated Poster - Area 3 (Joint): Tomographic Imaging for Therapy Localization

SU-DD-A3-01

Kernel Classification for Assessing Inter-Fraction Motion in IGRT

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Purpose: To develop a method that identifies an IGRT imaging session as either normal or problematic based solely on the amount of right-left, anterior-posterior, and superior-inferior repositioning of the patient over the treatment session. **Methods and Materials:** A retrospective data set containing over 1100 anterior-posterior, right-left lateral, and superior-inferior patient shift values for 29 prostate patients was examined using a non-parametric kernel regression classification method to determine if a patient was "normal" or "problematic." The treatment sessions were grouped as either being "normal", or affected because they were

"overweight", or had "rectal filling", or were both "overweight and had rectal filling". In kernel regression, constants are fitted using a locally weighted criterion. The basis of kernel regression is to estimate a response using a weighted average of points, in a training set, which are local to the query point. A bandwidth is used to determine the definition of local. Leave one out cross validation (LOOCV) was used to select the optimal bandwidth and also evaluate the technique's performance. **Results:** The method correctly classified 24 of the 29 patients using their respective shift data sets, with four of the misclassifications occurring when the technique correctly identified non-normal datasets, but assigned them to the wrong problem group. Only one patient was classified as normal incorrectly. **Conclusion:** Using readily accessible shift data, the kernel regression classification method was able to correctly identify the cause behind IGRT positioning problems for individual prostate patients. This technique is fully automated and can be implemented on a treatment planning computer to determine the reason a patient is having positioning errors early during treatment.

SU-DD-A3-02

Evaluation of Helical Tomotherapy Megavoltage CT System for Daily Automatic Patient Setup Correction and Manual Prostate Gland Motion Correction

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Purpose: To evaluate the efficacy of helical tomotherapy megavoltage CT system (MVCT), and to study patient setup uncertainty and inter-fractional internal organ motion for prostate cancer patients during the course of external beam treatment. **Method and Materials:** 34 prostate cancer patients that received definitive helical tomotherapy treatments were included in this study. MVCT images were registered with planning CT images using automatic bone registration followed by manual registration based on soft tissue match. Patient setup corrections and internal organ motion corrections in the medial-lateral (ML), superior-inferior (SI), anterior-posterior (AP) directions, and rotations around the longitudinal axis were obtained from 1345 daily MVCT image registrations. **Results:** The mean and standard deviation of patient setup corrections were 3.1±7.3 mm in the ML direction, -0.8±4.9 in the SI direction, –0.2±6.4 in the AP direction, and 0.8±1.3° for rotations around the longitudinal axis. The mean and standard deviation of internal organ motion corrections were –0.1±0.8 mm in the ML direction, -0.1±0.7 mm in the SI direction, and 0.0±1.9 mm in the AP direction. The fraction of manual registrations that did not have adjustment in the ML, SI, or AP direction was 84%, 95%, and 71%, respectively. The prostate motion variability did not change during the course of treatment. **Conclusion:** Patient setup uncertainty dominated target position uncertainty. Helical tomotherapy MVCT system was effective in correcting patient setup errors and internal organ motions in the ML and AP directions, but provided limited soft tissue resolution in the SI direction.

SU-DD-A3-03

A Dose-Guided Adaptive Therapy Process for Treatment Evaluation and Correction

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Purpose: To develop an adaptive therapy process for off-line radiotherapy evaluation and modification. **Method and Materials:**
An adaptive therapy process was developed to analyze and adjust a patient treatment. This included:

Daily Online Processes
- Daily CT imaging
- Patient repositioning

Weekly Offline Processes
- Automatic dose recalculation on each daily image
- Automatic deformable registration of each image with the planning image
- Automatic deformation-based recontouring of each image
- Automatic deformation-based dose accumulation
- Cumulative plan evaluation
- Replanning, as needed

The on-line imaging and repositioning was performed with the TomoTherapy MVCT system and integrated registration software. The off-line processes were performed on a standalone workstation.
Head and neck cases were studied with this process. Cumulated doses were typically analyzed at the end of each week, and modifications were performed mid-course. Remaining treatments were then performed with the adapted plan. **Results:** It was found that CT-guided soft-tissue positioning alone did not protect against dosimetric changes due to patient weight loss. Without plan adaptation, the right parotid gland would have received a dose of 10 Gy above the plan, due to its medial motion towards the target region. However, since mid-course adaptive replanning was used, the dose was only 2.5 Gy above the original plan. The use of an additional plan adaptation could have further reduced this discrepancy. **Conclusion:** An adaptive therapy process was developed for off-line contouring, dose recalculation, dose accumulation, and replanning. This process was applied to clinical head and neck patients to evaluate on-going treatments, adjust plans, and retrospectively assess the results. This process reduced unexpected parotid dose for these patients. This process also indicated that ability to recalculate to accumulate doses on daily CT images is important for addressing systematic errors, such as anatomical changes, that may arise during a treatment.

Supported by TomoTherapy,Inc.

SU-DD-A3-04

Quantitative Evaluation of Cone Beam Digital Tomosynthesis (CBDT) for Image-Guided Radiation Therapy

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Purpose: Cone beam digital tomosynthesis (CBDT) is a new imaging technique proposed by us recently as a rapid approach for creating cross sectional images of a patient in the radiotherapy treatment room. Similar to the cone beam computed tomography (CBCT) approach, the CBDT uses an X-ray source and an X-ray detector on a Linac to acquire projection data by rotation around the patient. Unlike CBCT, CBDT utilizes partial scans, typically in the range of 20-60 degrees of gantry arc. The purposes of this work are (1) to evaluate quantitatively the image quality of CBDT in terms of signal-to-noise ratio and spatial resolution; (2) to demonstrate that we can use CBDT to image soft tissue targets, e.g., the prostate. **Method and Materials:** An experimental CBDT system has been built on a Linac with a recently developed flat-panel detector. A number of phantoms including a spatial resolution phantom, two contrast-detail phantoms and a custom-made anthropomorphic pelvic phantom (CIRS Inc.) were used in the evaluation. CBDT phantom images have been generated and analyzed for different degrees of gantry arc and compared to those from CBCT. **Results:** Quantitative results on signal-to-noise ratio and spatial resolution have been obtained for different degrees of gantry arc. Compared to CBCT, CBDT has a worse spatial resolution in the direction perpendicular to the planes of reconstruction but a better resolution in the parallel direction. The image quality of CBDT is acceptable in the planes most relevant to the treatment. It has been shown that the prostate is visible on CBDT reconstructed images of the pelvic phantom. **Conclusion:** This work indicates that the CBDT approach can be a viable and rapid tomographical imaging technique for treatment verification in radiotherapy. **Conflict of Interest:** This work was partially supported by Siemens Medical Solutions, Inc.

SU-DD-A3-05

Evaluation of Respiration-Correlated Digital Tomosynthesis for Soft Tissue Visualization

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Purpose: To find optimal parameters for digital tomosynthesis (DTS) image acquisition, assess DTS imaging for soft tissue visualization and patient positioning, and determine if DTS can be acquired fast enough to avoid blur caused by the respiratory motion **Methods and Materials:** We

have used Varian gantry-mounted kV on-board imaging system to acquire DTS images as well as reference cone-beam CT (CBCT) scans. An external respiratory monitor system recorded patient respiration together with the x-ray on/off signal during imaging for retrospective sorting of projections based on respiration phase. DTS reconstruction used backprojection followed by a deblur. For a lung tumor subject to the respiratory motion we also reconstructed DTS images during a short time interval (~ 1 s = 6° arc at 1 rpm) around the end-exhalation.
Results: Phantom studies indicate that image quality increases with DTS arc length; however, longer arc lengths cause image blur and degradation. Optimal DTS arc length is 10-20.° Patient studies also indicate that at approximately 15° arc length image quality, as judged visually, is the best. For longer arcs image blur increases, while for shorter arcs out of plane objects become more pronounced. For all arc lengths tumor visualization was possible. Both manual and automatic 2D registrations of DTS and CBCT were possible in most cases. For short (6°) or long (30°) arc lengths manual registration became more challenging and automatic registration less precise, but still possible. Registration of a respiratory correlated DTS image over a 6,° non-optimal arc, was possible. **Conclusions:** DTS is capable of soft tissue and bone visualization and can be an efficient imaging modality for image-guided radiotherapy. DTS can be acquired, with some tradeoff in image quality, during a ~1s time interval, allowing reduction of respiratory motion artefacts. **Conflict of interest:** Research sponsored by NCI Grant P01-CA59017 and Varian Medical Systems

SU-DD-A3-06

Assessment of Lung Tumor and Diaphragm Motion Using Cone-Beam CT and 4DCT

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Purpose: To determine the variability in diaphragm and tumor motion assessed at planning and for each treatment fraction for patients with inoperable early stage non-small cell lung cancer treated using stereotactic body radiation therapy (SBRT). **Method and Materials:** Six patients with upper lobe lung tumors were treated using SBRT. For each patient, tumor motion was assessed initially using fluoroscopy on a conventional simulator. The subsequent scanning session involved a helical scan and a four-dimensional CT (4DCT) scan to assess tumor motion at the inspiration and expiration phases of breathing. Each of the three treatments was performed under on-line cone-beam computed tomography (CBCT) image guidance. Similarly to 4DCT, the projections for the CBCT scans were sorted based on an internal surrogate of the breathing cycle to provide volumetric datasets at the inspiration and expiration phases of breathing for each treatment fraction. **Results:** For five of the six patients treated, lung tumor and diaphragm motion measured on the treatment unit using CBCT was consistent with the tumor motion measured by 4DCT at planning. However, for the sixth patient, diaphragm motion, and to a lesser extent tumor motion, was markedly different between planning and the three treatment fractions. For this patient, the average tumor motion difference observed between 4DCT and projection-sorted CBCT scans was 4.5 mm (A/P) and the average diaphragm motion difference was 12.0 mm (A/P) and 9.5 mm (S/I), respectively. **Conclusion:** Our study has shown that the relative motion and position of the tumor at the time of treatment may not match that of the planning scan. Application of breathing motion data acquired at scanning time to modulate or gate radiation therapy may not be suitable for all patients. **Conflict of Interest:** Princess Margaret Hospital is part of the Elekta Synergy Consortium. The research is supported, in part, by Elekta Inc.

Exhibit Hall F

Imaging Moderated Poster Session

Moderated Poster - Area 4 (Imaging): Breast Imaging

SU-DD-A4-01

Quantifying Skin Effects After Accelerated Partial Breast Irradiation Using Digital Infrared Imaging (DII): Preliminary Feasibility Data

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Purpose: Accelerated partial-breast irradiation (APBI) is an emerging radiation technique that challenges standard whole breast irradiation. The larger fraction sizes used in these hypofractionated schedules may increase the risk of late normal tissue effects. Identification of the causes of variability in radiation sensitivity and normal tissue reactions could have important implications for breast cancer therapy. For this, a quantitative method of estimating early and late skin effects is needed. DII is recording instantaneous skin temperatures that are directly correlated with the skin blood flow, a parameter known to be an indicator of skin reaction. **Material and Methods:** An infrared digital camera IRSnapShot® was used to image breast cancer patients treated with APBI to a total dose of 3850 cGy over 10 fractions. The plans consisted of multiple external non-coplanar photons +/- electron beams. The patients were imaged in a controlled temperature room before and after each fraction. They were also be imaged at regular intervals during their follow-up. Two sets of orthogonal DII images were taken. The images were then transferred into Matlab where a GUI is being developed for image registration, thresholding and data analysis. **Results:** Five patients were imaged as described, three treated with photons only, and two with a combination of photons and electrons. The increase in maximum skin temperature from the baseline (pre treatment) to treatment completion is on average 2 to 4 degrees and depends on the techniques used, higher for plans including electrons, as expected due to their way of depositing dose. **Conclusions:** DII generated skin temperature information is a promising quantitative tool to estimate early and late effects in irradiated breast cancer patients. Our goal is to generate an "Index of Radiosensitivity" based on the early pattern of change in skin temperature that will allow individualization of radiotherapeutic prescription.

SU-DD-A4-02

A Novel Optical Imager Towards Breast Cancer Diagnosis

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Purpose: To design and develop a portable optical imager for early-stage breast cancer diagnostics, providing great depth information, enhanced data acquisition rates, and minimal patient discomfort. **Method and Materials:** A unique measurement geometry of simultaneous multiple point source illumination was implemented in the design and development of the hand-held based optical probe. Simultaneous multiple point detection was carried out using an intensified charge-coupled camera (ICCD) that can be operated in the continuous wave and frequency domain measurement approaches. The hand-held based imaging probe has been coupled to the ICCD detection system and the performance characteristics (in terms of measurement accuracy and precision) of the imager is characterized through initial phantom studies under homogeneous conditions. **Results:** Preliminary simulated studies using simultaneous multiple point illumination measurement geometry over the universally used single point illumination geometry demonstrated an increase in the detected signal strength as well as total interrogated tissue volumes. An optimal number of source and detector fibers used to develop the probe head, minimized the dead volume and improved the data acquisition times. **Conclusion:** A novel fluorescence-enhanced imaging system was developed using a hand-held probe and an ICCD camera, enabling the flexible and rapid imaging of any given tissue volume. Further work involves phantom based experimental studies towards 3D optical imaging and tomographic analysis. The final goal is to translate the current laboratory-based techniques into routine clinical use.

SU-DD-A4-03

Optimization of Mammography Linear Grid Geometry

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Purpose: Anti-scatter grids have been commonly used to reduce the amount of scatter in mammography. However, using grids require increasing the radiation dose to the breast in order to have an acceptable exposure to the image receptor. We used Monte Carlo simulation to optimize liner grid design for mammography imaging in a way to achieve best contrast improvement with lowest dose to the breast. **Materials and Methods:** We used Monte Carlo Simulation Code MCNP5 to determine the amount of Scatter to Primary Ratio (SPR) for different x-ray tube peak voltage (kVp), breast thicknesses, and grid geometries. We used a

Molybdenum target/Molybdenum filtered x-ray spectra, materials and geometrical dimensions that closely mimic the clinical situation. We used a semicircular shaped breast phantom made of 50 % adipose and 50 % glandular tissue equivalent materials. The grid septa were made of lead and inter-space was made of carbon fiber. **Results:** Our calculated SPR values agree within 5 % with previously published clinical data. We have obtained significant contrast improvement for low bucky factors. For a 5 cm thick breast equivalent phantom, we found an optimal septa height of 0.9mm, septa thickness of 12μm and an inter-space thickness of 100μm gives an optimal combination of 0.2 SPR, a 2.43 bucky factor, and a 1.31 contrast improvement factor (8 % error). With this geometry, the maximum SPR was lowered from 0.58 without the grid to 0.2 with the grid. **Conclusion:** We have optimized the geometry of the linear grid and achieved very significant contrast improvement with low SPR while minimizing the bucky factor and hence the mean-glandular dose to the breast.

SU-DD-A4-04

Measurement of Patient Specific Doses in Mammography

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Purpose: This study's aim was to develop an easily reproducible clinical protocol to predict the average glandular dose (AGD) delivered to patients during routine mammography screening. It incorporates an evaluation of patient specific features, including glandularity, to predict the clinically delivered dose for both the cranio-caudal (CC) and the medio-lateral oblique (MLO) views. **Method and Materials:** The development of a modified homogenous dosimetric breast tissue equivalent phantom series (BRTES-MOD) based on anthropomorphic measurements of the screening mammography population is central in evaluating the patient's fibroglandular content. It has been constructed with reference to the breast tissue elemental composition tabulated in the International Commission on Radiation Units and Measurements - Report 44, and simulates the compression and variable content of patient's tissue characteristics. This study calculates the average glandular dose using entrance skin exposure and dose conversion factors based on fibroglandular content, compressed breast thickness, volumetric and anatomical factors, mammographic unit parameters and modifiable parameters of the BRTES-MOD phantom. **Results:** Dose conversion factors were successfully calculated from the patient's fibroglandular content, compressed thickness, unit parameters, and spectral half value layer. An anthropometric population study facilitated the derivation of clinically usable equations to determine patient whole breast area, estimate patient skin layer thickness, and assess optimal placement for the automatic exposure control ionization chamber location. Dose distributions for the study population are presented for both CC and MLO views and compare well with those derived from previous population studies. **Conclusion:** The designed protocol can be performed within the time of a typical mammography screening appointment, and allows the determination of patient-specific average glandular dose. The BRTES-MOD method also provides a quantitative measure of patient specific AGD for the multiple projections comprising screening mammography examinations.

SU-DD-A4-05

Characterization of X-Ray Scatter and Glandular Dose in Digital Tomosynthesis for Breast Imaging Using Monte Carlo Simulations

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Purpose: To study the characteristics of x-ray scatter and glandular dose in digital tomosynthesis for breast imaging. **Method and Materials:** Monte Carlo simulations of x-ray transport in breast tomosynthesis were performed using the Geant4 package [Agostinelli et al, Nucl Instrum Meth A 506: 250-303, 2003]. Scatter-to-primary ratio (SPR) maps, maximum SPR, scatter point spread functions (PSF) and glandular dose to the breast were computed at several projection angles while varying compressed breast size, thickness, glandularity and x-ray spectrum. For validation, the SPR and scatter PSF for the planar mammography view (0 degrees) for various setups were compared with published values [Boone et al, Med Phys 27(10): 2408-16, 2000 and 27(8): 1818-1831, 2000]. **Results:** SPR maps and PSF show variations with increasing projection angle, with apparent asymmetry appearing at projection angles beyond 10 degrees. When the projection angle is increased from 0 to 21 –degrees, while the breast thickness encountered by the central ray increases by 7.1%, the maximum SPR for a semi-circular 10 cm radius breast increases by 10.1% and 18.8 % for breast thicknesses of 2 cm and 8 cm, respectively. Dose deposition shows a decrease, varying by 3.8-7.6% for the same thicknesses and projection angles. **Conclusion:** Since the use of an anti-scatter grid is not easy to implement in tomosynthesis imaging, the development of software-based post-acquisition scatter reduction is important, which requires a good understanding of the scatter effects. This work characterizes the scatter signal present in tomosynthesis images and shows that x-ray scatter affects each projection angle differently and therefore each projection must be corrected separately, using appropriate prior knowledge. Decreased glandular dose with increasing projection angle must be taken into account when planning a tomosynthesis clinical protocol. **Research supported in part by:** NIH-NIBIB Grant RO1-EB002123 and the Georgia Cancer Coalition.

SU-DD-A4-06

Visualization of Micro-Calcifications in a Prototype Breast CT Scanner

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Purpose: To evaluate the ability of a prototype breast CT scanner to detect micro-calcifications, and to understand the influence that tube potential and radiation dose have on this. **Method and Materials:** Commercially available micro-calcifications (μCa) of various sizes (200 to 425 μm) were embedded inside a 12.7 mm polyethylene tube filled with gelatin (to simulate glandular tissue). The gelatin tube was then placed inside a 14 cm diameter adipose equivalent cylindrical phantom and scanned using various tube potentials (60 to 100 kVp) and tube currents. CT images were reconstructed with both Ramp and Shepp-Logan filters, with a reconstructed voxel size of about 320×320×200 μm. The μCa were then evaluated quantitatively using signal-to-noise ratio (SNR) metric, and subjective appraisals were made as well. A dedicated breast CT visualization workstation was used for subjective evaluation. **Results:** Results for 250-280 mm μCa imaged at 80 kVp shown that the μCa are clearly visible when the rod is scanned by itself, but extremely difficult to locate when placed inside the 14 cm phantom. The visualization of the μCa improved overall for larger μCa, and overall visualization improves as the radiation levels are increased, as expected. **Conclusion:** These initial results suggested that the pixel size may not be a critical factor when determining the ability of the prototype system to visual micro-calcifications, as the current objects scanned are only about 48% of the reconstructed voxel size. Maximum intensity projection (MIP) display for thick-slice imaging was found to be most useful for subjective viewing of micro-calcification clusters.

Exhibit Hall F

Therapy Moderated Poster Session

Moderated Poster - Area 1 (Therapy): Stereotactic, Single and Hypofractionated Treatment I

SU-EE-A1-01

Calibration of a Cobalt-60 Irradiator for Stereotactic Radiosurgery Following the AAPM TG51 Protocol

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Purpose: Compare calibration of the Leksell Gamma Knife according to the American Association of Physicists in Medicine Task Groups 21 and 51 protocols. **Materials and Methods:** The Gamma Knife calibration phantom (The Phantom Laboratory, Inc., Salem, NY) is designed to fill with water and support an Exradin (Standard Imaging, Inc., Middleton,WI), model A-16, ionization chamber positioned at its center. The phantom and chamber assembly was mounted in a Leksell stereotactic ring. The location of chamber's sensitive volume was determined using computed tomography and the Leksell fiducial frame. The chamber-phantom assembly was attached to the 18 mm helmet in the Gamma Knife by the stereotactic ring. The phantom's geometry allowed radiation beams from

each of the 201 Gamma Knife cobalt-60 sources to converge along an 8 cm path to the ionization chamber's sensitive volume. This is equivalent to the arrangement by which one calibrates the Gamma Knife using the manufacturer-supplied polystyrene phantom. **Results:** The phantom could be attached to the Gamma Knife so that the ionization chamber was reproducibly positioned at the convergence of the beams. Because of the phantom's design, either trunnions or automatic patient positioning system could attach the phantom. Comparisons using different phantoms and protocols resulted in the following calibration ratios for TG-21 in the polystyrene sphere phantom, TG-21 in the water phantom and TG-51 in the water phantom, respectively: 1.00, 1.010, 0.996. Transmission measurements using a block of identical material indicate that the phantom's 2mm plastic shell would result in an error of approximately 0.6% if ignored. **Conclusions:** Calibration of the Gamma Knife can be performed in liquid water using the AAPM TG-51 protocol, thereby eliminating any uncertainties with respect to the composition of the polystyrene from. Calibration values for the Gamma Knife that were obtained using the three methods for our phantoms agree to within 1.4%.

SU-EE-A1-02

Analysis of Photon Beam Data From Multiple Institutions:An Argument for Reference Data

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Purpose: Beam data requirements to support sophisticated treatment planning and delivery techniques are increasingly rigorous. Small field photon measurements are particularly challenging for many centers and practitioners. The purpose of this work is to compare measured beam data characteristics from identical linear accelerators contributed by multiple institutions. Methods and Materials: Measured beam data from 43 "identical" 6 MV linear accelerators were collected from 43 different institutions. A common treatment planning system was used by all participating institutions, standardizing the data collected and simplifying the analysis. Beam data consisted of percent depth dose (PDD), cross-beam profiles and relative scatter factors (SF) as a function of field size. Beam data for field sizes less than 1 x 1 cm^2 were contributed by the majority of institutions. A dose-to-monitor unit conversion factor was also obtained. All data were normalized in a consistent manner for direct comparison. Data were analyzed using a commercial analysis package. Mean, standard deviation, minimum and maximum deviation were calculated for the PDD data. A one-population t-test was applied to PDD, scatter factors and dose-to-MU factors to identify statistically significant differences. **Results:** PDD data for a 10x10 cm^2 field size were remarkably consistent among institutions, with 1σ variation of less than 1% at all depths beyond d_{max}. In contrast, significant variation was observed in small field PDD data; at 0.6x0.6 cm^2, the PDD at 10 cm fell outside the 95% confidence level at 63.2% of institutions. Measurement of small field output factors proved to be equally variable. Several significant outliers were noted in dose-to-monitor unit conversion factors. **Conclusions:** Significant differences exist in beam data collected by multiple institutions for identical linear accelerators. Uniform procedures are needed to increase the quality and consistency of measured beam data. Use of a reference set of beam data may help to eliminate fundamental errors.

SU-EE-A1-03

A Novel Three-Dimensional Radiochromic Film Phantom for Use with Stereotactic Radiosurgery Units

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Purpose: To create a three-dimensional (3D) film dosimeter capable of simultaneously measuring the entire relative dose distribution of the volume fields of an Elekta Gamma Knife (GK) unit.

Methods and Materials: A spherical head phantom was constructed out of Virtual Water™ (VW™). This phantom was constructed with a bored hole allowing the insertion of a stack of film 2.5cm in thickness and 5cm in diameter. The hole is fitted with two unique fiducial rods that prevent both rotation and inversion of the film. Radiochromic film with a thickness of 105 microns is used, allowing approximately 240 layers of film to be inserted into the phantom. One layer of film is assumed to be water/tissue equivalent; however, the water/tissue equivalency of a thick stack of film has not been determined. Monte Carlo MCNP5 methods were used to determine the water/tissue equivalency of a thick stack of radiochromic film. **Results:** Using MCNP5 simulations, the water/tissue equivalency of a stack of film 2.5cm thick was determined. For a simplified model of the film phantom, the dose distribution in the active layer of the pieces of film was found to be within -1.7% of the dose distribution in similar layers of VW™, demonstrating that a stack of radiochromic film may be used as 3D dosimeter.**Conclusion:** Using a stack of film as a 3D dosimeter limits the resolution of the determination of the relative dose distribution only by the resolution of the scanner and by the thickness of the film layers. This allows resolutions of 50x50x105 $microns^3$ to be achieved. Most 3D dosimeters require advanced imaging equipment to read out the data but a 3D film dosimeter allows any institution which has a flat bed scanner to obtain 3D dose distribution information.

SU-EE-A1-04

Verifying Internal Target Volume Using Cone-Beam CT for Stereotactic Body Radiotherapy Treatment

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Purpose: The internal target volume (ITV) could be determined using 4D CT simulation images and be verified in the treatment room using on-board cone-beam CT (CBCT) since the CBCT projection images are acquired over approximately 10 breathing cycles. This study used a 4D dynamic phantom to verify the accuracy of this technique and also to develop a procedure for using CBCT to clinically verify ITV in stereotactic body radiotherapy (SBRT) treatment. **Method and Materials:** A CIRS 4D dynamic phantom, with a target ball and precisely controlled motion, was imaged using a 4D CT scanner. A Varian RPM system was used for respiratory gating. Ten 3-D image sets were generated corresponding to 10 breathing phases. The ITV was determined based on the phase images. To assess concordance, on-board CBCT images of the target ball were compared with the 4D-CT defined ITV. SBRT patient with tumor targets located in the thorax and upper abdomen were similarly scanned using phase gating 4D CT. The ITVs were compared between simulation CT and CBCT scans to identify localization error. **Results:** The dynamic phantom motion was 20mm along the inferior-superior direction, 5mm along the anterior-posterior direction, and 2mm along the left-right direction with a cycle time of 4 seconds. The concordance of the CBCT and ITV matching was within 1 mm. For the lung SBRT patient, the target volume based on the CT images without respiratory gating was 0.7 cc. The ITV was 2 cc. The ITV matches well with the CBCT images. The localization errors between free-breathing CT and CBCT were 2 mm to the right, 1 mm to the anterior, and 2 mm to the superior. **Conclusion:** CBCT provides an accurate assessment of the ITV for targets affected by respiratory motion.

SU-EE-A1-05

Determination of Beam Margins for SRT/IMRT of Small Lung Cancers Based On Monte Carlo Simulations

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Purpose: This work investigates the beam margins used in treatment planning for stereotactic radiotherapy (SRT) and intensity-modulated radiotherapy (IMRT) of small lung lesions based on Monte Carlo (MC) simulations. **Method and Materials:** Ninety SRT/IMRT treatment plans generated in a commercial treatment planning system were recalculated using MC simulations with different combinations of beam margin (0 to 18 mm), lung density (0.1 to 0.5 g/cm3) and planning target volume (PTV) (10 to 50 cc) based on the patient geometries built from CT images. Each plan was normalized at D_{95}, of the dose-volume histogram (DVH) so that the comparison between different plans could be made quantitatively in terms of minimum dose (D_{99}) and maximum dose (D_1) in the PTV. The relationship between the beam margin and lung density/tumor size was fitted into modeled functions. The beam margin needed for a particular plan with certain lung density and PTV size can be determined based on the clinical acceptance criteria based on maximum/minimum doses and other normal tissue constraints. **Results:** The maximum and minimum doses were found to vary with beam margins, the volumes of PTV and lung densities. The relationships between them have been quantitatively generalized into functions from the simulation data. It was found that the maximum dose decreased with increasing beam margin while the minimum dose increased with beam margin when the beam margin was less than 1.5 cm. The trends were reversed with the increasing PTV volume.

Conclusion: The generalized formulas for maximum and minimum doses can be used for the estimation of the minimal beam margin required in SRT/IMRT for adequate dose coverage for small lung tumors.

SU-EE-A1-06

IMRT Dose Gradients For Extracranial Stereotactic Radiosurgery

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Purpose: To compare IMRT treatment techniques for a simulated para-spinal mass located in the thoracic spine of an anthropomorphic phantom and to measure the accuracy of Megavoltage-CT (MVCT) images for localizing spinal anatomy in the T-Spine region. Methods and Materials: Treatment planning CT images were acquired on a kilovoltage CT simulator of a whole body anthropomorphic RANDO phantom and used to create a planning target volume (PTV) covering the T7 to T9 vertebral bodies. The fixed gantry IMRT cases were planned using the Pinnacle treatment planning system and delivered on a Varian 21EX with a 120-leaf multileaf collimator. Inverse treatment plans were created with 9 and 12 equally spaced fixed fields starting at 0-degrees (IEC Scale). Inverse planning was performed using Direct Machine Parameter Optimization (DMPO), and gradient decent optimization with sliding window leaf sequencing. Helical tomotherapy cases were planned using the TomoTherapy HI-ART treatment planning system. Relative dose measurements were made using calibrated film placed in the RANDO phantom. MVCT images of the RANDO phantom were acquired with a tomotherapy system and fused with the treatment planning CT images. The phantom was then correctly positioned, and the fusion error was measured by imaging the T7 and T9 phantom vertebrae. A principal component analysis was used to determine the largest factors in image registration. **Results:** The 9-Field DMPO and helical tomotherapy cases had PTV uniformities of 10% and maintained a large dose gradient. **Conclusions:** Helical tomotherapy and 9-Field DMPO treatments yielded similar dose gradients (10%/mm) and PTV dose uniformity indices (10%). The sliding window treatment deliveries were consistently worse in cord sparing and dose uniformity. Anthropomorphic phantom studies indicated that megavoltage CT images were capable of imaging the spine for placement at isocenter within 1-mm of the desired position.

Exhibit Hall F

Joint Imaging/Therapy Moderated Poster Session

Moderated Poster - Area 2 (Joint): Correction Strategies

SU-EE-A2-01

Minimizing Residual Target Motion for Imaging Guided IMRT Delivery

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Purpose: IMRT delivery could be affected by residual target motion, the intrafractional target uncertainties resulting from motion that follows image-guided procedures such as dual x-ray image acquisitions with patient positional corrections. This study investigates the 6D spatial characteristics of residual target motion and a method for minimizing potential IMRT delivery errors. **Method and Materials:** A recursive dose painting algorithm was developed to reorder MLC segments, so that most segments were delivered repetitively at a fraction of its prescribed MU. The rationale is that there could be residual target motion that would cause significant delivery errors, so to"paint" the target voxels recursively in small dose segments instead of painting the whole area once with a larger dose segment, could produce a more accurate delivery. The residual target motions used were determined from implanted spine fiducials detected using the dual x-ray images taken every 10-20 seconds during treatment (Cyberknife, Accuray). Six-degree of freedom spatial characteristics of the residual target uncertainties were extracted. These residual motions were then fed into the recursive dose painting method for dose evaluation. **Results:** The residual target motion study showed that although the average was less than 3 mm during the whole delivery, there existed large irregularities in distributions in both rotational and translational directions. For most cases, there were also systematic motion errors of 0.5-1 mm and large spurious motions, sometimes of 5 mm or more. When using the actual error-time curves, the recursive delivery significantly reduced dose variations caused by such errors (by as much as 27%). For the majority of cases studied, a cycle of three to six repetitive dose paintings was found sufficient to achieve such improvements. **Conclusion:** Residual target motion is irregularly distributed as treatment time progresses. Recursive dose painting provides a solution to decrease the dose errors caused by such uncertainties.

SU-EE-A2-02

Feasibility of Tracking Head Position Under An Obscuring Immobilization Mask Using a Bite Block and a 3-D Surface Imaging System

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Purpose: To assess the accuracy and feasibility of measuring head motion under a thermoplastic immobilization mask when using a 3-D surface imaging system. **Materials and Methods:** Small dome-shaped objects were arranged asymmetrically on a styrofoam platform that was attached to a bite block system. The assembly was mounted on the couch of a linear accelerator to a micromanipulator with slow motion controls. This arrangement is operationally similar to a bite block affixed to the maxilla of a intracranial radiation therapy patient. The micromanipulator allowed for motions with six degrees of freedom. We were able to achieve sub-millimeter translational adjustments of the bite block assembly and angulation. The platform and objects were "tracked" with the AlignRT® 3-D surface imaging system (VisionRT, London, UK) in order to compare mechanical translational and rotational movements of known magnitude with the changes reported by the AlignRT system. While translational motions are only reported with millimeter resolution on the computer control screen, we obtained the system records sub-millimeter from stored data file records. **Results:** Translational agreement between the micromanipulator and the AlignRT system was 0.1±0.1 mm in all three axes. Rotational agreement was within 0.5 degrees for pitch and roll. Agreement for yaw was not determined, however the display for couch rotation is 0.1 degree and has a stability of ±0.1 degrees. **Conclusion:** The AlignRT surface imaging system has superior accuracy that is sufficient for stereotactic radiosurgery guidance using a bite block as we have designed the experiment. Combining a bite block similar to what we designed with the AlignRT 3-D system shows promise in monitoring head position under an occluding immobilization mask.

SU-EE-A2-03

Evaluation of Auto-Segmentation Tools for the Target Definition for the Treatment of Lung Cancer

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Purpose: With the advent of more sophisticated image devices in the treatment room, image guided radiotherapy (IGRT) and adaptive radiotherapy (ART) have become distinct possibilities. IGRT and ART techniques in their various stages have been implemented in clinics. One of the ART techniques using the daily acquired CT images involves re-planning due to the target shape variation during the treatment. Lung cancer volumes of some cases are observed to undergo significant changes where re-planning is a necessity. To be able to define target efficiently can help the treatment flow significantly. This study evaluates various auto or semi-auto contouring tools either commercially available or under development for their accuracy and ease of use. **Method and Materials:** Three methods are included in the study. Two are commercially available (Focal,CMS): auto threshold (of gray level); and auto Segmentation where gray level, the edges and prior shape information are used. The third method is the ITK-SNAP program that uses a powerful level set(snake) segmentation algorithm to segment anatomical structures in three dimensions. **Results:** Ten image sets from helical and cone beam CTs are included in the study. The acceptable contours are defined as those with distance to agreement to those drawn by radiation oncologists less than 3 mm. For target volume surrounded by normal lung, the percentage slices of contours that do not need manual adjustment are 41-62%, 23-39%, 62-78% for threshold, auto segmentation and SNAP respectively. For cone beam CT, these numbers are approximately 10% lower. SNAP can also be used for target volume with no clear boundary, although the percentage success is much lower. **Conclusion:** More sophisticated auto-

segmentation tools need to be available routinely with more flexibility for users to adjust algorithm parameters in order for them to be useful for routine clinical ART purposes.

SU-EE-A2-04

A Method of Online MLC Aperture Adjustment for Treatment of Patients with Set Up Variations

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Purpose: To investigate MLC aperture adjustments to compensate patient setup variations, replacing couch shift methods for precision treatment delivery. **Method and Materials:** Patient setup variations can be described by 3-D translational shifts. A scheme of adjusting MLC apertures to compensate for translational displacements of the patient has been developed. Patient shift information, such as provided by commercial image matching software, establishes the aperture shift vector. The projection of this vector into and orthogonal to the BEV plane was used to determine the displacement vector and divergence for the aperture. Modified beam apertures were generated and MLC leaf positions were determined through a polynomial interpolation.
Dosimetric plan comparisons were made within Pinnacle 7.6c. Static field and segmented IMRT patient plans were investigated for pelvic as well as head and neck sites. Arbitrary shift vectors ranging from 3 mm up to 30 mm have been investigated. Non-integral MLC leaf width shifts parallel to the leaf bank face to characterize leaf width effects. **Results:** Conformal plans show dose variations from the original plan of up to 3% in the pelvis for shifts of up to 30 mm. Dose coverage of the PTV was maintained except in the superior-inferior direction, where coverage in the last 3 mm of target fell as low as 92% of the prescribed dose. Results for prostate and oropharynx IMRT plans showed little increase in maximum critical structure doses, and small increases in mean doses. DVH's for IMRT plans confirmed minimal impact on critical structure doses. **Conclusion:** An alternative method of on-line adaptive treatment delivery has been explored which eliminates the need to adjust the patient position. This can potentially increase treatment accuracy and efficiency through minimizing patient disturbances and reducing the time between imaging and treatment.

SU-EE-A2-05

Direct Aperture Optimization for On-Line Adaptive Radiation Therapy

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Purpose: To investigate a novel technique for on-line adaptive radiation therapy (ART) that uses direct aperture optimization (DAO) **Methods and Materials:** A model simulating the geometry of a prostate case was created. The prostate, rectum and bladder are represented by an ellipsoid, cylinder and sphere, respectively (the dimensions and positions of these structures are based on patient image data). This configuration represented the "original geometry" and was used to create the original IMRT treatment plan. The plan was created using an in-house DAO system with seven beams (40, 80, 110, 250, 280, 310, 355 gantry angles) and six apertures per beam. Four different "deformed geometries" were created by systematically deforming the original geometry to various degrees (0.25, 0.50, 0.75 and 1.00 cm maximum deformations of rectum and prostate). For each deformed geometry, a new treatment plan was created by modifying (adapting) the original treatment plan using DAO. The quality of the resulting plans, together with the optimization time efficiency of the plan adaptation, was used to assess the suitability of DAO for on-line ART. The effects of altering different DAO parameters were investigated by varying the maximum leaf step size, maximum aperture weight change and optimization cooling schedule. **Results:** The plans created by adapting the original treatment plan met the imposed dose constraints for all four deformed geometries. Adapting the original treatment plan was much faster than performing a completely new re-optimization. Furthermore, by appropriately limiting selective DAO parameters the convergence to an acceptable plan was significantly accelerated. The optimal choice of DAO parameter limits was correlated to the degree of geometry deformation. **Conclusion:** This study demonstrated that DAO is highly suitable for on-line ART. The treatment plan adaptation was efficient and the resulting plans met the imposed dose constraints.

SU-EE-A2-06

Benefit of 3D Image-Guided Stereotactic Localization in the Hypofractionated Treatment of Lung Cancer

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Purpose: To investigated the benefit of image-guided stereotactic localization for lung cancer patients treated with hypofractionated radiotherapy. **Materials & Methods:** A stereotactic body localizer (SBL) was used for patient immobilization, image registration among multi-phase CT simulation, and image-guided stereotactic localization. The simulation scans consist of 3 sets of CT images taken during free breathing and 2 breath-holding scans (at maximum inhalation and exhalation). Target delineation was performed on all 3 sets of images and the combination of the targets forms a composite gross-target volume (GTV). Treatment planning was performed on the planning-target volume (PTV) using 3 mm margin to account for the presumed reliability of the CT localization. Prior to each treatment, a localization CT scan using a CT-on-rails was obtained. Couch shifts were made based on the changes of the stereotactic coordinates of three pre-selected bony landmarks. In this retrospective treatment dose verification, we performed image fusion between the simulation CT scan and each pre-treatment CT scan to obtain the same target and critical structure information. The same treatment plans were re-loaded onto each pre-treatment CT scan with their respective stereotactic coordinate system. The changes in dose distributions were assessed by dose-volume histograms of the PTV and the critical structures before and after isocenter corrections which were prompted by image guided stereotactic localization. We compared D_{95}, D_{99}, and V_{95} for the PTV and GTV, and $V_{20}$and V_{30} for the ipsilateral lung. **Results:** Our retrospective study for 10 patients with 40 dose reconstructions showed that the average D_{95}, D_{99}, and V_{95} of the PTVs are 92.1%, 88.1%, and 95.8% of the planned values before isocenter corrections. With the corrections, these values are all improved to 100% of the planned values. **Conclusions:** 3D image guidance is crucial for stereotactic radiotherapy of lung tumors when small margins are used.

Exhibit Hall F

Joint Imaging/Therapy Moderated Poster Session

Moderated Poster - Area 3 (Joint): Molecular Imaging & Image Registration / Fusion

SU-EE-A3-01

A Novel Filtering Approach for Local PET Verification of Proton Radiotherapy

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Purpose: Proton radiotherapy activates positron emitters in tissue, which can be imaged with PET. However, the resulting PET image is not directly proportional to the delivered dose. We are investigating the spatial relationship between the dose distribution and its PET image without reverting to Monte Carlo methods. The first goal is to validate the proton range in the patient, and ultimately to reconstruct the spatial distribution of the actually delivered dose from its PET image. **Method and Materials:** The relationship between the proton dose and its PET image can be described mathematically as a convolution (filtering). We derive the convolution kernel analytically. This filter is unique for a given activation channel, independent of beam energy and specific absorber. The straightforward application of the method to determine the PET signal by locally filtering the planned dose distribution was validated through comparisons with Monte Carlo calculations and measured PET data in homogeneous and inhomogeneous media. The challenging inversion of the relationship, determining the dose from the PET signal, was initially explored for a simplified mono-energetic case in a homogeneous absorber. **Results:** Activity depth profiles obtained with the convolution approach agreed with measured and Monte Carlo data within 1 mm in depth. In terms of absolute intensity, the agreement was within 1.5% between filtered and simulated profiles and 10% between filtered and measured data in the distal region. Attempts to recover the dose distribution from its PET image

through a de-convolution yielded promising results for idealized data but were strongly noise dependent. **Conclusion:** We have derived the spatial relationship between dose and positron activation and demonstrated the possibility to obtain the PET image measured after proton treatment by locally filtering the planned dose distribution. The inverse approach, i.e., direct dose quantification from the measured PET, seems possible but is very sensitive to noise.

SU-EE-A3-02

The Potential of FDG-PET in Delineating the Lumpectomy Cavity for Partial Breast Irradiation Patients

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Purpose: To investigate the potential of FDG-PET imaging for delineating the surgical cavity in post-operative partial breast irradiation patients. **Method and Materials:** A DCIS breast cancer patient was imaged with a GE Discovery ST PET-CT scanner approximately 2 weeks post lumpectomy. Following the treatment planning CT, a single-bed (15 cm) FDG-PET scan was dynamically acquired in 5-sec intervals over 15 mins. The raw PET data was combined to form bins ranging from 30 sec to 15 min. These data were reconstructed by the GE scanner through an iterative OSEM algorithm, and hardware fused to the treatment planning CT. The value of PET in visualizing the lumpectomy cavity border was investigated through visual comparisons of fused PET-CT images, the evolution of PET intensity for various breast points, and signal-to-noise measurements across the lesion. **Results:** The PET image showed clear signal enhancement near the lumpectomy cavity. This enhancement formed a ring in each axial slice, matching the locations of surgical clips. Enhancement was also apparent where the cavity border was difficult to evaluate by CT density or clips alone. The ring presented a significantly higher SUV than other breast tissue (2.2 vs. <1.4), while the region inside the ring had a lower SUV than the (presumably benign) glandular tissue in the same breast (1.2 vs. 1.4). The SUV values were transient below 5 min, but remained stable thereafter. **Conclusion:** FDG-PET may provide useful information for delineating lumpectomy cavity borders by elucidating regions of enhanced radiotracer uptake due to inflammation. The hypointense PET volume enclosed by the high activity ring may represent fluid and non-viable tissue stemming from post-surgical changes, explaining its lower FDG uptake and further supporting the suggestion that the ring corresponds to the cavity border itself. On current hardware, five-minute scans were required to achieve stable SUVs.

SU-EE-A3-03

A Biomechanical Lung Deformation Model Based On MR Grid-Tagging Using Hyperpolarized 3He

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Purpose: Deformable image registration is critical for advancements of lung tumor radiation. Commonly used mathematical deformable registrations do not provide actual biomechanical trajectories of anatomical motion. Therefore, we developed a biomechanical registration model (BRM) based on hyperpolarized ^{3}He MRI grid-tagging to automatically segment structures and generate BRM encoded cine CT images. **Method and materials:** Normal volunteers underwent hyperpolarized ^{3}He MR imaging on a 1.5T whole-body MR scanner. Grid-tagging was achieved by applying sinc-modulated RF pulses with a composite flip angle of 90° prior to the acquisition of the images followed immediately by a multi-slice FLASH-based acquisition at full inspiration and exhalation. For each slice, a displacement vector was computed for each grid element. The complete lung motion was based on spatial and temporal interpolation of the displacement vectors. The motion and deformation of anatomical structures were obtained using the interpolated vector field through various phases. The displacement vectors were registered to a coronal CT image to generate a set BRM encoded cine CT images. **Results:** Tagging signals were well preserved and sufficient for quantitatively resolving the tag motion. From the displacement vector map, the lower lobes exhibit the greatest motion magnitude especially in the craniocaudal direction. The motion of the structures driven by the displacement map is continuous and smooth. No substantial artifacts in the BRM generated dynamic CT images were observed. **Conclusions and Discussion:** BRM provides an independent measure of lung motion and deformation. Compared to pure-mathematically constructed registrations, BRM relies on fewer assumptions and avoids errors induced by image matching processes. BRM encoded dynamic images are useful to cross-validate deformable registration by other imaging modalities and algorithms. We plan to explore the potential of this methodology for auto segmentation and treatment planning.

SU-EE-A3-04

Deformable Registration for In Vivo Imaging and Pathology Correlation

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Purpose: To describe a deformable registration infrastructure to resolve the geometric discrepancies between in vivo imaging studies and histology from resected tumor specimens to reduce uncertainties in tumor definition. **Method and Materials:** An IRB approved prospective study investigating the correlation between in-vivo CT and MR imaging, ex-vivo specimen imaging and pathologic sections from colorectal cancer liver metastases treated by resection was developed to better define gross and clinical tumor volume. Triphasic liver CT scans, PET-CT scans and MR scans were obtained in 6 patients within 4 weeks prior to liver resection. On the day of surgery, the fresh liver hepatectomy specimen was imaged using MR. The specimen was fixed and reimaged with MR prior to pathological evaluation. Axial sectioning was done at the time of pathological evaluation, with photos of each liver slice digitized. Histological evaluation was performed on the sections representing the largest tumor. Gross tumor was identified on all images sequences. Gross tumor, microscopic tumor and vascular changes of interest were also identified on the gross and histological pathological specimens. A finite element model-based deformable modeling algorithm, MORFEUS, was used to resolve the geometric discrepancies due to changes in the position of the liver between each imaging sequence and session through a guided surface projection and finite element analysis. **Results:** Deformable registration can be used to facilitate comparison of imaging to pathological specimens. In the liver, substantial specimen shrinkage and deformation were seen necessitating deformable image registration. The accuracy of MORFEUS to relate the pathology-histology to the in vivo imaging was within the slice thickness (5 mm) of the pathology sectioning, determined via identified vessel bifurcations in the liver. **Conclusion:** An accurate deformable modeling infrastructure has been established to relate the geometric position of the liver and excised liver specimen on different imaging modalities and histology.

SU-EE-A3-05

Accuracy Testing of Deformable Registration Using Dosimetric End-Points

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Purpose: To develop a dose-based evaluation method to assess deformable image registration accuracy **Method and Materials:** An algorithm developed for deformable registration of MVCT to kVCT images was evaluated. The algorithm allows the generation of automatic contours on MVCT images by transferring the kVCT contours using the deformation map. The automatically generated MVCT contours can thus be used to test the deformation algorithm by comparing these contours with manual contours. Instead of a geographic contour comparison, dosimetric endpoints were evaluated after the dose distribution was calculated in the MVCT images. Three dosimetric endpoints (D_{max}, D_{mean}, and Dose to the hottest 2 cc ($D_{max\ (2cc)}$) were compared for spinal cord contours. The evaluation of geometric end-points is directly related to the clinical information that needs to be evaluated if daily images are used for adaptive radiation therapy. A total of 93 daily megavoltage CT (MVCT) images from three patients treated for cancers in the head and neck region were evaluated. **Results:** Averaged over all images the calculated D_{max} differed between the automatic and manual contours by 1.1 % with a standard deviation of 3.5 %. The respective values for D_{mean} and $D_{max(2cc)}$ are 0.1 ± 2.5 % and 1.8 ± 2.4 %. Maximum deviations between the dosimetric endpoints were 12 % for D_{max}, 8% for D_{mean}, and 13 % for $D_{max(2cc)}$. **Conclusions:** Using deformable image registration, dosimetric end-points

can be generated from automatic contours in the spinal cord region that differ from manual contours by 1-2 % on average with a standard deviation of 2.5 to 3.5 %. In the spinal cord region the developed deformable image registration appears to provide sufficient accuracy to support clinical decisions. **Conflict of interest:** Research supported by the vendor that is commercializing the algorithm. Several co-authors are vendor employees.

SU-EE-A3-06

Deformable Image Registration in Cone-Beam CT Images for Image-Guided Adaptive Radiotherapy

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Purpose: With the availability of on-board imaging devices capable of constructing cone-beam CT (CBCT) images, it is expected that there will be great interest in using volumetric CBCT for image-guided adaptive radiotherapy. In order to fully utilize CBCT, automatic segmentation on CBCT images is one of key steps toward this goal. . The purpose of this study is to implement a robust deformable image registration for auto-segmentation. **Method and Materials:** In four head and neck cancer patients, we used our previously developed, image intensity-based deformable image registration algorithm to register the planning CT with the 3-5 daily CBCT in three scenarios. First, the daily CBCT was directly used without modification. Second, we applied a generic look-up-table transformation to map the CBCT image intensity to the conventional CT intensity using the measured electron density calibration curves for both the conventional and CBCT scanners. In the third scenario, we proposed a wavelet-based dynamic window/level histogram matching algorithm to map the CT number from CBCT image to the conventional CT image. Then the deformable image registration was performed in the modified CBCT images to map the anatomical structures from the planning CT to the corresponding CBCT images. **Results:** Without pre-processing, we found that the CT numbers in CBCT images were inconsistent, especially in soft tissue regions and in patients with large body circumferences. The deformable image registration using the window/level histogram matching method performed the best with good consistency in delineating soft tissue structures. The algorithm is also computationally efficient. **Conclusion:** We implemented a wavelet-based window/level histogram matching algorithm to pre-process the CBCT to allow for more robust deformable image registration of with the reference planning CT. This implementation allows for volumetric CBCT-guided adaptive radiotherapy.

Exhibit Hall F

Imaging
Moderated Poster Session
Moderated Poster - Area 4 (Imaging): Computed Tomography

SU-EE-A4-01

CT Number Accuracy of Lung Nodules: Effect of Patient Body Size and Lung Size

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Purpose: To investigate the effects of patient body size and lung size on the CT numbers of lung nodules measured with multi-detector CT scanners and whether improved accuracy can be obtained with a dual-energy technique. **Method and Materials:** Simulated lung nodules consisting of 9.5-mm diameter spheres containing 50mg/cc and 100mg/cc $CaCO_3$ in a water-equivalent resin were scanned in two simulated thorax section phantoms with a GE VCT scanner. One phantom (A) represented the middle of the chest. It had large simulated lung regions and simulated ribs, heart and spine. The other (B) represented the upper chest. It had a much wider aspect ratio, smaller simulated lung regions, and simulated ribs, scapula, heart, and spine. Fat rings were added to the phantoms to simulate larger patients. Images were acquired on a GE VCT scanner with high-resolution techniques (0.53:1 pitch, 0.625-mm slice thickness and interval) at 80, 120 and 140kVp. Scans were repeated 3 times for reproducibility and analyzed using an automated technique. **Results:** Body size had a significant effect on the measured mean CT-numbers of the nodules. For phantom-A, adding fat rings decreased the overall average CT-numbers of the 50mg/cc nodules at 120kVp by 15HU and those of the 100mg/cc nodules by 21HU. Corresponding reductions in phantom-B were 9HU and 13HU. The dual-energy approach (CT#80kVp-CT#140kVp) reduces the variability, with a maximum difference of 4HU for all conditions. Lung size had a minimal effect with a maximum difference (nodule CT# phantom A - nodule CT# phantom B) of 4.5 HU. **Conclusion:** Even with modern multi-detector CT scanners, beam hardening and x-ray scatter errors due to body size can result in underestimates of the true CT numbers of lung nodules. A dual-energy approach compensates for these errors and should be considered especially if it can be implemented using a rapid kVp switching technique.

SU-EE-A4-02

Stochastic Noise in CT Images

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Purpose: Because diagnostic Computed Tomography (CT) imaging involves a tradeoff between image quality and radiation risk, there is great interest in determining the effects of stochastic noise on the utility of clinical tasks. The reconstruction processes used in CT result in noise properties that are non-local and anisotropic in the image domain. A commonly used approximation for computing image noise from raw measurement data was empirically tested for validity. A noise variance mapping scheme was used to estimate stochastic noise in complex anatomical scenes and was compared to variance measurements of image simulations generated with controlled amounts of synthetic noise. **Methods:** The commonly assumed transformation between linear and log variance ($\sigma^2=1/Q$) was tested for Poisson random numbers with means ranging from less than one to larger than 30. Noise variance maps were generated by filtered back projection using the square of the reconstruction kernel operating on sinogram variance estimates. A series of images was reconstructed by adding Poisson noise to sinogram data, and the variance of regions of interest in the image sequence was calculated. **Results:** The approximation that log variance is proportional to the inverse number of quanta fails badly for $N<10$. Estimated variance maps were found to agree with empirical measurements of image variance. The noise variance in a CT image is a slowly varying spatial function. Image simulations demonstrated that noise has a texture that is highly anisotropic and can mimic anatomic structures. **Conclusions:** CT noise is a complex phenomenon. Variance maps are a useful tool for estimating noise in structured image regions where direct variance measurements fail. Fortunately most clinical scans operate at higher flux levels where the commonly used variance approximation is valid. Low-dose protocols must be carefully evaluated to determine the effects of stochastic noise on diagnostic performance.

SU-EE-A4-03

Spatial Resolution-Matched Comparison Between Fan-Beam and Cone-Beam X-Ray CT Images

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Purpose: Cone Beam CT (CBCT) kilovoltage imaging devices are increasingly available for daily imaging in radiotherapy departments. Flat-panel based CBCT scanners present a distinctive set of artifacts due mostly to increased scatter, longer data acquisition time and reduced detector quantum efficiency as compared to helical Fan Beam CT (FBCT) systems. Our purpose is to characterize image quality from FBCT and CBCT scanners based on noise, contrast and dose, using FBCT as a benchmark. **Method and Materials:** we acquired phantom and clinical patient images with a CBCT Varian On-Board Imager as well as with a FBCT Picker PQ5000 single-row helical scanner. The CBCT scanner was equipped with antiscatter grid and bowtie filter. By comparing CBCT and FBCT images of a high contrast resolution insert, the CBCT reconstruction voxel size and filter were adjusted until the spatial resolution of the FBCT and CBCT images was approximately matched. Dose was measured with standard CTDI and Farmer chambers. Noise, contrast and SNR were evaluated and compared. **Results:** CBCT images of both phantom and patient were relatively free of streaking and cupping artifacts, indicating that the grid had successfully attenuated most of the scatter. Low contrast detectability threshold is similar for the two modalities, when CBCT dose is about twice

as large as FBCT. Noise and non-uniformities are more prevalent in patient CBCT images, but pelvic soft tissue structures are well discernible. For patient and phantom images Dose×SNR^2 is about 4 times lower for FBCT than in CBCT, which is about 1.5-2 times larger than expected, given the measured grid transmission and detector quantum efficiency. **Conclusion:** In this study, resolution-matched CBCT and FBCT images could exhibit similar SNRs and contrast-to-noise ratios through a combination of increased imaging dose and reduced spatial resolution.

SU-EE-A4-04

Phase and Amplitude Binning for 4D-CT Imaging

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We compare the consistency and accuracy of two image binning approaches used in 4D-CT imaging. In 4D-CT the images and respiratory motion are correlated via RPM Respiratory Gating system (Varian, Palo Alto, CA). In phase binning (PB), RPM assigns each breathing cycle 2π radians, within which the images are grouped. Alternately, the images are assigned bins according to the signal's amplitude (AB). To quantitate both approaches, we used NEMA NU2-2001 IEC phantom oscillating at random frequencies and amplitudes, simulating patients breathing. 4D-CT images were obtained using 4-slice GE Lightspeed CT operating in cine mode. We define consistency error as ability to correctly bin over breathing cycles in the same FOV. Average consistency error in PB ranged from 18%±20% to 30%±35%, while in AB the error ranged from 11%±14% to 20%±24%. For 28mm sphere, PB images were hardly consistent, with error of 43%±47%, while AB images for the same sphere resulted in error of only 18%±22%. In PB, while not all breathing cycles covered all phases, nearly all bins contained sphere slices. AB was more accurate, revealing empty bins where no sphere slices existed. As a proof of principle, we present examples of two NSCLC patients' 4D-CT lung images binned by both approaches. While AB can lead to gaps in the images, depending on patients' breathing pattern, PB exhibits no gaps but suffers visible artifacts due to misbinning, yielding images that covered a relatively large amplitude range. AB was more consistent, though often resulting in gaps corresponding to CT slices where no data existed due to patients' breathing. We conclude AB is more accurate than PB, which should be factored into treatment planning and diagnosis.

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SU-EE-A4-05

Effects of Cone-Beam CT Noise and Cupping Artifacts On Deformable Image Registration

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Purpose: Image-guided adaptive radiotherapy proposes to use sequential CT studies to track anatomical change during treatment via deformable image registration. These CT studies can be acquired with either conventional fan-beam CT systems or more novel cone-beam CT techniques. However, cone-beam CT images can have higher noise levels and more imaging artifacts than fan-beam CT, which might impact registration accuracy. We have investigated the effect of these image quality differences on the deformable registration of fan-beam and simulated cone-beam CTs. **Method and Materials:** Our study used two fan-beam CT studies of a prostate patient, taken ten days apart. A deformable image registration process was used to register the two studies and then transfer treatment planning contours from one CT to the other. The accuracy of the automatically-transferred contours (and thus of the deformable registration process) was assessed by comparing them to manual contours, with the differences evaluated with respect to inter-observer variability in the manual contours. Then one of the fan-beam CTs was modified to include higher noise and cupping artifacts characteristic of cone-beam CT and the tests were repeated. Changes in registration accuracy were detected by monitoring changes in the automatically-transferred contours. **Results:** We found that the additional noise and the cupping artifact caused no appreciable loss of registration accuracy at magnitudes up to and exceeding what would normally be found in an actual cone-beam CT. **Conclusions:** We conclude that deficiencies in cone-beam CT quality that might reduce manual contouring accuracy do not necessarily reduce image registration and automatic contouring accuracy.

SU-EE-A4-06

A Novel Approach for Metal Artifacts Reduction Due to Tooth Filling

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Introduction: The aim of this study is to present a conceptually new method for metal artifact reduction (MAR), especially for patients who have multiple metal objects with small sizes. Metallic implants such as dental fillings cause serious artifacts in reconstructed CT images. Although the previous methods based on conventional projection-interpolation successfully reduced artifacts in the case of large metal objects such as hip prostheses, their performance appears to depend highly on the complexity of the structures examined and they are very sensitive in correctly detection of missing projections resulting still many artifacts in the final reconstruction for the case of multiple-near metal objects. Methods and Materials: The proposed method is based on modifying the raw CT data acquired during patient's examination. First, the projection data affected by metal objects (missing projections) are detected in sinogram using a simple thresholding algorithm. Then, the missing projections are replaced by corresponding 180 degrees projections, which are not affected by metal objects. The idea beyond the replacing scheme is due to the fact that the two projections along the same path but in the opposite sides would be the same in the absence of table motion. So, in the presence of table motion, like an helical CT exam, the opposite side projections still constitute very good approximations for the corresponding missing projections. In order to make the replacing scheme more reliable, we start the process simultaneously from each side of missing projections area. Finally, the modified sinogram is transferred back to the CT scanner device where CT slices are regenerated using the built-in reconstruction operator.
Experimental Results: The resulting tomography by the proposed approach show significant improvements in image quality, especially for regions near the metallic implants, compared to those by interpolation-based approaches.

Exhibit Hall F

General Poster Discussion
Imaging

SU-FF-I-01

Determination of Subjective Similarity for Pairs of Lesions On Mammograms: Comparison of Ranking Scores in 2AFC Versus Absolute Ratings for Masses and Microcalcifications

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Purpose: We previously obtained the subjective similarity ratings for pairs of lesions on mammograms for quantitative evaluation of similar images. Our purpose in this study was to investigate whether the absolute similarity ratings can be determined reliably by comparison with ranking scores obtained in a 2-alternative forced-choice (2AFC) method. **Method and Materials:** We selected 8 pairs of masses and 8 pairs of clustered microcalcifications based on radiologists' average similarity ratings; similarity ratings for the two sets of 8 pairs were approximately evenly distributed. In the first study, each pair was compared one by one to all other 7 pairs in each group of masses and microcalcifications. In the second study, we combined four pairs of masses and four pairs of microcalcifications to compare the similarity of a pair of masses with that of microcalcifications. Seven radiologists and 3 senior residents were asked to choose one pair that was more similar than another pair with the 2AFC method. The cases were presented in randomized order. The number of times that a pair was selected as more similar was counted as the subjective ranking score. The average scores were compared with the average similarity ratings determined previously. **Results:** The average ranking scores from the first study were highly correlated (0.93 and 0.98 for masses and calcifications, respectively) with absolute similarity ratings. When mass pairs were compared with calcification pairs, the correlations between ranking scores and absolute ratings were also very high (0.92 and 0.96). In both studies, observers were very consistent in selecting more similar pairs. **Conclusion:** The result indicates that absolute similarity

ratings determined previously are reliable and useful for selection of similar images. The concept of similarity is robust and meaningful even when mass pairs are compared with microcalcification pairs.

SU-FF-I-02

Entrance Exposures During On-Board KV Imaging

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Purpose: To estimate entrance exposure levels during on-board kV imaging (Version 1.2) on Trilogy (Varian Medical Systems). **Methods and Materials:** The patient was simulated by phantom using 40 cm and 20 cm of 40 x 40cm^2 water equivalent slabs. Exposure measurements were acquired for 80 and 90 cm source-to-surface distances using a 150 cc Fluke ionization chamber (96020C) and an Innovision 3050A dosimeter. The measurements were performed for various preset techniques that are commonly used in the clinic such as AP pelvis, Lat Pelvis, AP head, AP thorax, and AP extremity. Exposure rate levels were also measured during pulsed fluoroscopy with the automatic background control option activated. For comparison purposes, the exposure levels on a conventional simulator were also measured. **Results:** The entrance exposure levels on the on-board imager vary between 0.13 mSv for an extremity technique to 4.9 mSv for a lateral pelvis technique and were comparable to the conventional simulator measurements. On-board imaging pulsed fluoroscopy exposure levels were higher than those measured using the continuous fluoroscopy technique on the conventional simulator. **Conclusions:** Though the exposure and exposure rates are relatively low and inconsequential to the overall course of prescribed therapy, it is important to document exposures received. This documentation is essential for imaging protocols that may exceed normal imaging and localization exposure levels.

SU-FF-I-03

Computation-Efficient Cone Beam Image Reconstruction for Image-Guided Radiation Therapy Applications Using 3D Weighted Filtered Backprojection (CB-FBP) Algorithm

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Purpose: To extend the 3D weighted cone beam filtered backprojection (CB-FBP) algorithm for diagnostic CT imaging to image-guided radiation therapy (IGRT) applications. **Method and Materials:** 3D isotropic spatial resolution is one of the most attracting features of state-of-the-art volumetric CT for diagnostics imaging. However, in IGRT treatment planning, the CT image slice thickness is usually larger than what is determined by detector row width (namely thin image). A straightforward way to generate thicker image is the combination of weighted adjacent thin images in image domain, which is computationally expensive because each thin image has to go through a computation expensive 3D backprojection. Another way is to carry out cross-row filtering in projection domain, which may cause shading/glaring artifacts and uneven slice thickness as isotropic 3D geometry is distorted. To optimize both image quality (IQ) and computational efficiency, a virtual reconstruction plane (RP) based algorithm is proposed and implemented. By using the 3D weighted CB-FBP algorithm, a thick image is still a weighted combination of adjacent thin images, but the combination is implemented in projection domain using virtual RPs. To maintain the IQ of thick image, the 3D weighted CB-FBP algorithm is applied by tracking re-sampled projection data. The tracking process is to improve computational efficiency further by making use of the projection data corresponding to involved virtual RPs only, while the re-sampling process is to improve IQ by increasing the in-plane sampling-rate in virtual RPs. **Results:** By using a helical body phantom, spatial resolution phantom and 20 cm water phantom, the performance of the proposed algorithm, such as suppression of artifacts, uniformity of slice thickness and noise characteristics, are experimentally evaluated and verified. **Conclusion:** The experimental evaluation shows the proposed algorithm is indeed an optimized image reconstruction solution for IGRT applications in terms of both image quality and computational efficiency.

SU-FF-I-04

A Fast Variable-Intensity Ring Suppression Algorithm

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Purpose: Gain drifts and nonlinearities in amorphous silicon flat-panel x-ray detectors can produce ring artifacts in reconstructed cone-beam computed tomography (CBCT) images. We have found that the magnitude of these artifacts can exceed 50 HU in clinical situations, and that the intensity of a given ring may not be uniform throughout an image. In some cases (e.g. half-fan pelvic scans), discrete arcs may be produced. The goal of this study was to develop a post-processing algorithm to efficiently suppress such variable-intensity rings in axial slices. **Method and Materials:** Our approach builds upon the work of Sijbers and Postnov who showed that constant-intensity rings can be estimated via radial median filtering of the input image after its transformation to polar coordinates. To characterize variable-intensity rings and arcs, we developed a 2-D estimation technique that uses a combination of row-based (radial) and column-based (angular) filters operating in the polar domain. The 2-D estimates were transformed back to Cartesian space for subtraction from the original image. The new algorithm was implemented in C++ and tested on clinical and phantom CBCT images acquired using a Varian 4030CB detector. **Results:** Correction times (3.2GHz Intel Pentium4 processor), including coordinate transformations, averaged 55 msec/slice for 512x512 matrix sizes. Rings and arcs were reduced in intensity by more than an order of magnitude to levels well below the background noise intensity. By subtracting ring estimates in Cartesian space, the polar matrix size could be reduced without sacrificing spatial resolution in the final image. This permitted for a 4x reduction in execution time compared to the original Sijbers-Postnov approach where subtraction occurs in polar space. **Conclusion:** The Sijbers-Postnov algorithm ring suppression algorithm was modified to provide improved image quality and fast execution times suitable for clinical implementation. **Conflict of Interest:** Funding provided by Varian Medical Systems.

SU-FF-I-05

Hounsfield Units Calibration with Adaptive Compensation of Beam Hardening for a Dose Limited Breast CT System

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Purpose: Hounsfield Units calibration with adaptive compensation of beam hardening for a dose limited breast CT system. **Method and Materials:** Following a complete cone beam CT scan of the target object (a human breast), geometrical parameters of the object, including the mass center location and maximum radius from the mass center were calculated promptly. These parameters were used to compute X-ray projection images of a water cylinder based upon photon attenuation in the cylinder and detector response. Projection images of the target object were corrected prior to reconstruction by logarithmic subtraction of the water cylinder projection images. CT images relative to the Hounsfield Units (HU) scale were produced after cone beam reconstruction of the corrected projection images. Custom built water phantoms were tested with various inserts, including polyethylene, polystyrene, PMMA, nylon, polycarbonate and Teflon, with a density range from 0.92g/cm^3 to 2.2g/cm^3. **Results:** A wide range of breast diameters (10cm-18cm) and compositions (0%-100% glandular) were evaluated, and reconstructed and scaled HU values demonstrated excellent uniformity, linearity and consistency. Typical HU values were within 5% of theoretical values. The proposed method was applied to clinical breast scans. The "cupping" artifact caused by beam hardening in the original image was corrected as expected. **Conclusion:** Conventional methods of Hounsfield Units conversion are based on the scan of few fix-sized water phantoms and lack the flexibility to compensate for the beam hardening from objects with various sizes. The introduced noise from water phantom scans is also not negligible, especially for a dose limited breast CT system with much lower mAs than whole body CT systems. The proposed method can compensate for beam hardening over a wide range of breast diameters and compositions without increasing noise contents in the image.

SU-FF-I-06

A Portable Test Platform for Image Acquisition and Calibration for Cone Beam Computed Tomography (CBCT) and Region of Interest CBCT (ROI-CBCT) On a Commercial X-Ray C-Arm System

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Purpose: We have developed a unique portable test platform (PTP) which enables CBCT for specimens and phantoms on standard commercial clinical x-ray systems. This PTP can be used to acquire ROI-CBCT projection images, where a lower resolution, lower dose image peripheral to a high resolution ROI is acquired. This is achieved either by acquiring an image using an Image Intensifier (II) with an ROI filter in the x-ray beam or by combining images acquired separately with low and high resolution x-ray detectors. **Method and Materials:** The CBCT images are acquired as the object rotates on the computer-controlled rotary table of the PTP. For ROI-CBCT, a micro-angiography (MA) detector or an ROI filter is mounted on the PTP. The PTP also provides for relative X, Y, Z adjustments. After coarse alignment adjustments of the PTP, fine translational and angular adjustments are made based on fluoroscopic imaging of a cylindrical calibration phantom. **Results:** The PTP allows quick assembly of the parts required for CBCT or ROI-CBCT reconstruction, reduces initial setup time to < 45 min, and provides for setup reproducibility. The system can be aligned to within one pixel (43 micron for the MA detector), with angular alignments of pitch and roll of the object better than 0.7^0 and 0.1^0 respectively. **Conclusion:**, The PTP allows fast and reliable set-up and alignment of CBCT specimens, for standard and for ROI-CBCT applications. The PTP may enable wider use of CBCT and ROI-CBCT for specimens and phantoms without a costly dedicated system.

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SU-FF-I-07

Characterization of a Novel Anthropomorphic Plastinated Lung Phantom

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Purpose: To quantify the anatomical and imaging characteristics of a novel anthropomorphic lung phantom constructed using plastination. **Method and Materials:** The pig's thorax was scanned in-vivo at known partial pressures on a clinical CT (Siemens Sensation 16, 120kVP, 100mAs, recon 0.54x0.54x0.75mm^3). The lungs were extracted, inflated, and fixed by intra-tracheal perfusion of 10% formalin while the pulmonary vessels were injected with Silastic E RTV silicone. The specimen was dehydrated (remove and replace tissue fluid with an organic solvent) in cold acetone and the lungs were impregnated with a curable silicone polymer via slow decreasing pressure. Finally, the polymer was polymerized using a curing agent. The plastinated phantom was then scanned (120kVp, 200mAs, 0.43x0.43x0.75mm^3). Anatomical features, volume measurements, and CT values were compared using in-vivo and phantom clinical CT reconstructions. **Results:** The plastinated phantom is stable on the timescale of years and retains major anatomical features of the in-vivo lung. The phantom airway volume was 66% of the in-vivo measurement at inspiration but equal to the measurement at expiration. Vessel and lung volume comparisons were complicated by incompletely filled vessels and air pockets inside the phantom; nevertheless, lung volume measurements differed by less than 15%. Mean CT values of the cardiac tissue in the phantom (168 +/- 46) were 132 HU higher than in-vivo (36 +/- 87). Mean CT values of the pulmonary tissue were nearly equivalent for both datasets, attributed to an 11% decrease in the apparent tissue density due to over-inflation during plastination. **Conclusion:** This work shows that the novel plastinated lung phantom retains the anatomical and imaging characteristics of an in-vivo lung. This accurate and complex lung phantom has many uses including imaging system comparisons, providing a known, stable reproducible complex background for visibility studies and will be used for our own studies in lung tomosynthesis optimization.

SU-FF-I-08

Results of An Optical Fiber-Based Dosimetry System for Use in Computed Tomography Characterization

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Purpose: Modern multi-detector CT and cone-beam CT offer wide beams, making the concept of CT dose index (CDTI) no longer valid for CT dosimetry. A real-time OSL dosimetry system has been developed and is evaluated for CT dosimetry in this study. Comparisons with a pencil ionization chamber were made. Methods and Materials: The system utilizes the optically stimulated luminescence (OSL) of KBr:Eu. The size of the KBr:Eu single crystal dosimeter equals approximately 1 mm^3. The dosimeter was affixed to the terminal end of a plastic fiber cable and placed in the center hole of a plastic cylindrical phantom. The distal end of the fiber cable was attached to OSL reader, containing a 658 nm red laser, and photo-multiplying tube (PMT), and associated optics/ electronics. CT slices of 1 s duration were performed over a range of energies (80-140 kVp) and tube currents (60–350 mA), as well as slice thickness (5 and 10 mm) using a GE LightSpeed Ultra scanner. Gantry tilt dependence was investigated over a range of 40.5° (22° superior to 18.5° inferior). OSL data was obtained before, during, and after the scan at the rate of 10Hz. **Results:** Performance was determined in part by normalizing both the initial OSL intensity and the background-subtracted integral OSL to exposure reported previously by an ionization chamber. Good correlation between exposure and OSL data was found. Initial intensity and background-subtracted OSL normalized to exposure show coefficients of variation of ~%5 or less. Significant deviation was observed between the ~10 OSL measurements taken for each slice, presumably as a result of absorption of x-rays by the patient table. **Conclusions:** Initial tests have shown that this OSL dosimetry system possesses great potential for faster CT characterization. This system may prove a valuable alternative to CTDI.

SU-FF-I-09

Minimizing Scatter Artifact in Cone-Beam CT Reconstruction Using Both Kilovoltage and Megavoltage Beams

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Purpose: To study the effect of imaging orientations on image quality of aggregated conebeam CT and to develop a strategy to minimize scatter artifact. **Method and Materials:** Orthogonal kilovoltage (kV) and megavoltage (MV) beam projections were acquired and used to reconstruct kV/MV aggregated CT images. With a 15-degree fan-beam angle, only 105-degree gantry rotation s needed to obtain a minimal scan coverage. Besides its short scanning time, the new scan technique has the advantage of getting high soft-tissue contrast from kV beams and low scatter artifacts from MV beams. The kV and MV projection images were obtained by using a kV on-board imager and MV portal imager mounted orthogonally on a Varian-21EX LINAC. A linear model was established to fit the kV and MV attenuation values over the 15-degree overlap region. MV projections were then converted into kV-equivalent ones. Aggregated CT images were reconstructed from both kV and converted MV projections jointly, using the filter-back projection method. **Results:** Using 8 different kV/MV orientations, we reconstructed 16 aggregated CT images for two phantoms, eight for each one. Each image was registered to its corresponding simulator-CT image from a GE LightSpeed-RT simulator. The reconstructed images show good contrast for both bones and soft-tissue. However some of them have relatively severe scatter artifacts. We calculated the normalized mutual information (NMI) between the aggregated CT and simulator CT images. The NMI exhibits a sinusoidal oscillation when plotted against the gantry start angle. The two maximums correspond to the two imaging orientations with kV (or MV) beams through the thinner (or thicker) side views of the phantoms, indicating that scatter from kV beams has more impact on image quality than MV beams. **Conclusion:** A strategy has been developed to determine the optimal imaging orientation for aggregated kV/MV CBCT.

SU-FF-I-10

Compensators for Management of Dose and Scatter in Cone-Beam CT

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Purpose: Compensating filters have been considered for use in flat-panel based cone-beam computed tomography (CBCT) for the primary purpose of reducing the range of exposure reaching the detector. The use of compensators can also have other benefits, including reducing the magnitude of x-ray scatter reaching the detector, as well as reducing the x-ray scatter induced dose within the patient. The magnitude of these effects is characterized for a set of compensators constructed for clinical cone-

beam CT imaging geometries. **Method and Materials:** A set of copper compensators has been constructed with a range of modulation (1:1, 4:1, 8:1) for compensation of a cylindrical phantom (16 cm diameter). Investigations were performed on a bench-top flat-panel CBCT system that matches the imaging geometry (source-to-axis distance of 100 cm, magnification of 1.4 to 1.85) of clinical cone-beam CT systems used in radiation therapy. The influence of the compensators on scatter-to-primary ratio (SPR) at the detector (Paxscan 4030A, Varian Medical Systems) and dose within the phantom (NE 2571 0.6cc ion chamber) was measured. The influence of the compensators on reconstructed CBCT image quality (uniformity, accuracy) was assessed for cylindrical water baths. **Results:** Depending upon phantom size (16 or 32 cm) and imaging geometry compensation reduced x-ray scatter at the detector by up to a factor of two. Dose at the center of phantom was reduced by 25 to 35% for the same primary fluence along the beam midline. The reduction of scatter was correlated with a reduction in cupping artifacts, however, spectral hardening by the compensator introduced other non-uniformities in the water bath reconstructions. **Conclusion:** The implementation of simple compensators in CBCT has great potential for reducing x-ray scatter at the detector and patient dose. Further investigations will focus on determining the optimal compensation scheme for patient and task specific CBCT imaging.

SU-FF-I-11

Site-Specific Image-Gain Calibration for MV CBCT

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Purpose: MV CBCT is an image guidance modality which yields a 3D dataset representative of the patient anatomy in treatment position. During the acquisition, a series of low-dose projection images are generated by exposing a high detection efficiency flat panel to short bursts of the linear accelerator beam. In order to avoid image artifacts, the projection images need to be "gain" corrected for variations in pixel intensity unrelated to traversed patient anatomy. These variations arise from differences in individual pixel sensitivities, as well as from the spectral and the intensity non-uniformity of the incident beam. In this work, we propose and validate two treatment site-specific gain correction (GC) strategies. **Method and Materials:** The first GC approach employs an open-field in-air image of the beam. Each subsequently acquired image is then divided by this GC image (GCI) to remove the effects of differing pixel gains as well as of incident beam non-uniformity. The second approach acquires a GCI using a flattened beam. A tray with a 1/2 inch uniform lead plate is inserted in the accessory tray holder prior the gain image acquisition. The presence of the lead plate in the beam path results in spectral and spatial homogeneity of the beam incident on the flat panel imager. **Results:** The clinical scope of the two correction approaches was investigated by clinical MV CBCT acquisitions. In-air gain calibration is well suited for head and neck imaging since the underlying spatial and spectral properties of the beam remain unaltered. However, for prostate cases the second calibration approach significantly reduces image artifacts related to the coupled phenomena of beam hardening and profile flattening. **Conclusion:** Site-specific acquisition protocols that employ GCIs generated under different conditions result in substantial MV CBCT image quality improvement. **Conflict of Interest:** Supported by Siemens.

SU-FF-I-12

Validation of Geant4's Predictions On X-Ray Scatter and Glandular Dose in Pendant-Geometry Cone-Beam Breast CT

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Purpose: The Geant4 toolkit is a freely available, widely supported base package for the simulation of particles through matter. This study aimed to test Geant4's accuracy by comparing its predictions for glandular dose and x-ray scatter in pendant-geometry cone-beam breast CT against previously published experimental and simulated data. **Method and Materials:** We performed Monte Carlo simulations using the Geant4 package [Agostinelli et al, Nucl Instrum Meth A 506: 250-303, 2003] to recreate the conditions of three previously published papers on breast CT dose and scatter. Geant4's scatter simulations are compared against experimental data [Kwan et al, Med Phys 32(9): 2967-2975, 2005], while the dose results are compared against Monte Carlo simulations based on other codes [Boone et al, Med Phys 31(2): 226-235, 2004; Thacker et al, Phys Med Biol 49: 5433-5444, 2004]. The compared scatter results include scatter-to-primary ratio profiles for breasts of different sizes, glandularity and incident x-ray spectra. For the dose comparisons, we compared Geant4's monochromatic results with the monochromatic results reported by the two previously published papers. **Results:** Geant4 matches the reported experimental SPR profiles to an accuracy of 1.6-16.7% (μ=9.2%, σ=5.4%). The sources for observed deviations include inexact re-creation of the experimental setup and lack of specific information on the x-ray spectra used in the experiments. The dose results agree with Boone's published results within 0.7-12.3% (μ=5.3%, σ=4.2%) and with Thacker's to within 1.2-22.3% (μ=10.8%, σ=8.8%). **Conclusion:** The data comparison suggests that Geant4 can be used to predict x-ray scatter and dose deposition in low energy experiments such as dedicated breast CT. Given the availability, support and flexibility of the Geant4 toolkit, the use of this package for simulation of breast CT studies can be very useful to researchers in the field. Research supported in part by: NIH-NIBIB Grant RO1-EB002123 and the Georgia Cancer Coalition.

SU-FF-I-13

Dose Delivered to Patients for Megavoltage Cone-Beam CT Imaging

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Purpose: Megavoltage Cone-Beam CT (MVCBCT) has recently been introduced in the clinic to improve patient alignment prior to dose delivery. The objective of this research was to evaluate the dose delivered to patients for MVCBCT acquisition. We also studied the possibility of making simple plan modifications to compensate for the dose delivered by daily MVCBCT imaging. **Method and Materials:** Because MVCBCT uses the treatment beam, conventional CT scans (pelvis and head and neck patients) were imported in a treatment planning system (Phillips, Pinnacle) to simulate an MVCBCT acquisition. To validate the dose obtained from Pinnacle, a simple water-equivalent cylindrical phantom with spaces for MOSFETs and an ion chamber was used to measure the actual dose delivered during MVCBCT. **Results:** The MVCBCT dose delivered to the phantom, calculated from Pinnacle, was within 3% to all the MOSFET measurement points. The difference between Pinnacle and the ion chamber was 0.2%. For a typical MVCBCT (arc: 270° to 110°) the delivered dose forms an anterior-posterior gradient. Head and neck patients receive dose ranging from 0.7 to 1.2 cGy per MVCBCT monitor unit (MU). The range is 0.6 to 1.2 cGy per MVCBCT MU for pelvis patients. The total dose for daily positioning using MVCBCT can be reduced and made uniform by alternating between two opposed imaging arcs. Dose-volume histograms of a compensated plan for a pelvis patient imaged with 10 MU MVCBCTs for 40 fractions show no additional dose to the target and small increases at low doses. **Conclusion:** Given that clinical MVCBCTs are currently performed at doses ranging from 2-15 MU, simple plan modifications, such as reducing the total number of MU, can be used to nearly eliminate the dose used for daily positioning. Results for other body sites will also be presented. **Conflict of Interest:** Research sponsored by Siemens OCS.

SU-FF-I-14

Computed Tomography with Separate Primary and Scattered Radiation

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Purpose: Separating primary and scattered radiation in cone-beam Computed Tomography to improve image quality. **Method and Materials:** Earlier generations of CT uses narrow beams or fan beams of x-rays, which suffer little from scattered x-ray photons. Newer generations of CT systems, however, use cone-beamed x-ray beams are associated with large amount of scatter radiations that tend to blur the reconstructed images based on the radiation absorbed by the detectors. In the low-energy range (~100 kV) of x-ray photons involved in diagnostic imaging, the scatter-to-primary (SPR) is on the order of 1, as compared to megavoltage x-rays, where typical SPR is on the order of 0.1. Swindell and Evans (Med. Phys., vol. 23, p. 63, 1996) had computed that the central axis SPR is almost linear with beam area, and is also almost linear with depth in water for a

6MV beam. Three methods are proposed to separate primary and scattered radiation in cone-beam CT based on the ideas in the field of radiation therapy: (1) using a relationship between SPR and distance to the radiation source, in conjunction with a two-layer detector array; (2) using a pencil beam to sample primary dose; and (3) using Monte Carlo simulations to reconstruct primary and scattered radiation. **Results:** Simulations suggest that separate primary image and scattered images can be obtained, with the primary image at an improved image quality as compared with the image from the total radiation. **Conclusion:** Separate primary and scattered images can be obtained through mathematical means and a simple upgrade of detector array to achieve better images and more information. .

SU-FF-I-15

Effects, Detection and Removal of Zingers From Scattered X-Rays in CCD Based Cone Beam CT

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Purpose: Zingers are tiny spurious white dots that appear randomly in CCD images. In order to improve the quality of CCD based cone beam CT technique, a new technique for the detection and removal of zingers is described and evaluated. **Method and Materials:** A bench top CCD based cone beam CT system was used to measure and investigate the presence of zingers. The cause and effects of zingers were studied. A new technique was developed to detect and correct the zingers. With this technique, the statistical behavior of pixel values in a projection image was first analyzed to identify candidates for zingers. Pixel values at the detected zinger locations were then compared in two consecutive projection views to eliminate false detections. To investigate and evaluate this technique, zingers were simulated by increasing the pixel values at randomly selected locations in projection data computed for a modified Shepp-Logan phantom. The simulated data were then detected and corrected for zingers and used for reconstruction. The resulting reconstructed image was compared with the image reconstructed from zinger free data and with images reconstructed from data corrected using three other zinger removal techniques. **Results:** Our measurement indicated that zingers may have resulted from scattered x-rays. They were found to generate visible artifacts and degrade the quality of reconstructed images. It was shown that zingers detection by comparing two identically acquired projections could be highly effective but impractical in CT imaging. Detection by comparing two consecutive projection views was equally effective but may be subject image blurring. Detection by analyzing signal fluctuations could result in a large number of faulty detections. The proposed new detection technique was found to be practical and effective without resulting in image blurring or faulty detections.

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SU-FF-I-16

Volume-Of-Interest (VOI) Cone Beam CTwith Dual Resolution Image Acquisition

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In this study, we investigate the feasibility of using VOI projection data acquired at high resolution in conjunction with full width projection data acquired at low resolution to reconstruct cone beam CT images for the VOI. To simulate cone beam CT with dual resolution image acquisition, flat panel images of a mastectomy specimen, acquired in the non-binning mode, were converted into low resolution full width projection data. High resolution VOI projection data were directly extracted from the original data. To prepare for reconstruction, the low resolution projection data were first interpolated, re-sampled to fill in the truncated space outside the VOI. The dual resolution full width projection data, consisting of true high resolution data in the VOI and interpolated data outside the VOI, were then used to reconstruct the 3-D image for the VOI. Reconstructed images obtained with dual resolution projection data were compared with those obtained with low resolution data and those obtained with high resolution data for the visibility of small calcifications. We have successfully demonstrated the use of dual resolution projection data for VOI cone beam CT imaging. While the low resolution full width projection data did not allow smaller calcifications to be seen in the reconstructed images, addition of high resolution projection data for the VOI only could make them visible. The use of interpolated low resolution projection data to pad the truncated space outside the VOI did not affect the spatial resolution of reconstructed images inside the VOI. With the dual resolution technique, it would be possible to selectively image a VOI at very high resolution without requiring excessively long acquisition and reconstruction or unnecessarily overexposing the patient outside the VOI.

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SU-FF-I-17

Reduction of Set-Up Error Using Cone Beam-CT in Patients Undergoing Partial Breast Irradiation

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Purpose: Partial breast irradiation with multiple external beams requires accurate alignment of the target volume and treatment isocenter. On-board plannar kV/MV imaging can verify set-up based on boney landmarks. On-board cone beam CT (CBCT) may provide additional soft-tissue-based information to further improve set-up accuracy. In this study, we assess the utility of CBCT in patients receiving partial breast radiation therapy, who have been aligned with on-board plannar kV/MV imaging. **Method and Materials:** Patients undergoing partial breast irradiation were imaged using an on-board-imager attached to the gantry of a Varian 21EX machine. Each patient was aligned to skin marks in the treatment position. Orthogonal kV images were acquired and registered to digitally reconstructed radiographs from the planning CT. Subsequently, a CBCT image data set was acquired and compared to the planning CT using both boney anatomy and soft tissue information which yielded estimations of residual setup error. **Results:** 10 patients were studied under an IRB protocol. Each patient had an average acquisition of 9 pre-RT CBCT images. After 2D kV image registration based on boney anatomy, the average soft tissue residual error, based on the CBCT vs. planning CT, was 4, 2, and 3 mm in the Ant/Post, Sup/Inf, and Rt/Lt directions respectively. The ranges were 0-15, 0-9, and 0-7 mm, respectively. In one case, 30% of the planning tumor volume (PTV) would have been outside of the therapeutic isodose volume based on the pre-RT CBCT images. **Conclusion:** CBCT is a practical tool for image registration while visualizing the soft tissue of the tumor bed. It provides additional anatomic information and soft-tissue detail beyond that provided by planar radiographs. Such increased accuracy can significantly improve dosimetric coverage of the planning target volume. **Conflict of Interest:** Partially supported by a Varian research grant

SU-FF-I-18

Quantifying the Geometric Accuracy of the On Board Imager Over a One-Year Period

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Purpose: To quantify the geometric accuracy of the On Board Imager in both the kV radiographic and cone beam imaging modes. **Method and Materials:** The Winston-Lutz test was performed to localize a 5mm tungsten sphere placed within +/- 0.25 mm of the radiation isocenter. The sphere was imaged with half fan cone beam scans, and kV radiographs at the 4 principal gantry angles. The displacement of the sphere from the 'imaging isocenter' (the actual position of a point object that the imaging system would find to be at isocenter) was determined for each imaging mode. This test has been repeated 18 times over a period of one year. **Results:** The average displacement of the sphere from the imaging isocenter using a half fan technique was found to be 0.9 mm Right, 0.9 mm Anterior, and 1.1 mm Inferior, assuming a head first supine orientation. These offsets are incorporated in image-guided patient setup procedures. Small systematic errors as a function of gantry angle were also measured for the radiographs. A point at the radiation isocenter will appear about 1mm higher in a right lateral image than in a left lateral image. A similar left / right discrepancy exits for anterior and posterior images. **Conclusion:** The systematic geometric errors of the kV imaging equipment and associated techniques need to be measured and incorporated into the

procedure of on-line image-guided patient treatment. For the On Board Imager, a geometric accuracy of better than 1mm can be achieved.

SU-FF-I-19

A Study of Megavoltage Beam Tomosynthesis

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Purpose: To study the impact of projection numbers on the quality of tomosynthesis images using megavoltage beams. **Method and Materials:** It has been shown that isocentric kilovoltage tomosynthesis images can be generated with no more than 50 degree scan angle. With only one seventh of scan time and dose of CBCT, this new technology can generate on-board images with comparable quality as CBCT to guide patient's positioning. In this study, we used megavoltage (MV) beam projections to reconstruct tomosynthesis images. The MV projection images were acquired by using a MV portal imager mounted on a Varian-21EX LINAC. The high-resolution mode was used for acquisition and it required less than 1 cGy dose for each projection. The raw projections data needed background and floor image corrections and was then taken to generate tomosynthesis images by using the FDK cone-beam reconstruction algorithm. **Results:** Compared with kV tomosynthesis images, MV tomosynthesis images also give good contrast for bones. However, for soft tissue, their contrast is relatively lower. We calculate normalized mutual information (NMI) between MV and kV tomosynthesis images and studied its dependence on scan angle and angular interval. The experiment shows that with the angular interval fixed, NMI increases as the scan angle grows and with the scan angle fixed, NMI decreases as the angular interval increases. For our study on a spine phantom, 50-degree scan angle and 1-degree angular interval gives good trade-off between images quality and projection numbers. **Conclusion:** MV beam can be used to generate good quality tomosynthesis images.

SU-FF-I-20

Digital Tomosynthesis Mammography (DTM) : Dependence of Reconstruction Image Quality On Number and Angular Range of Projection Views

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Purpose: We have previously found in a phantom study that a simultaneous algebraic reconstruction technique (SART) could achieve similar image quality to maximum likelihood reconstruction, but with fewer iterations. In this study, we applied SART to patient and breast phantom images and evaluated the reconstructed image quality when the number and the angular range of the projection views (PVs) were varied. **Method and Materials:** A second generation GE prototype DTM system was used for image acquisition. PVs are acquired from 21 angles in 3º increments over a ±30º range in less than 8-sec. The DTM system uses an Rh/Rh x-ray source for all exposures. The total dose of the 21 PVs is set to be about 1.5X of that of a single-view mammogram at the corresponding breast thickness. The phantom is composed of four 1-cm-thick breast-shaped slabs of heterogeneous or homogeneous mixtures of fibroglandular-and-fatty-tissue-mimicking material with embedded masses. A 5x6 array of contrast-detail disk-shaped holes were drilled on one of the homogeneous slabs. DTMs were reconstructed with all 21 PVs, or subsets of the PVs to simulate different angular ranges and increments. The use of subsets of PVs resulted in a reduction in the total dose of the reconstructed DTM in this study. The image quality of the reconstructed DTMs under different conditions was compared. **Results:** For both the phantom and patient DTMs, image sharpness and contrast decreased with decreasing numbers of PVs used in the reconstruction. The interplane artifacts increased with decreasing angular range of the PVs. **Conclusion:** The image quality of DTMs depends on the number of PVs and the angular range used in image acquisition. Further investigation is needed to evaluate trade-offs between the angular increment and angular range, as well as the effects of reconstruction parameters on image quality when the number of PVs varies.

SU-FF-I-21

Two-Dimensional Shift-And-Add (SAA) Algorithm for Digital Breast Tomosynthesis Reconstruction

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Purpose: To investigate a two-dimensional Shift-And-Add algorithm for three-dimensional digital breast tomosynthsis reconstruction to correct for defects existing in the traditional Shift-And-Add algorithm that calculates only one-dimensional shift amount along the axis of x-ray tube's motion. **Method and Materials:** With the traditional Shift-And-Add (SAA) algorithm for breast tomosynthesis reconstruction, shift amounts for each projection plane are calculated only along the axis of x-ray tube's movement. As a result, small objects such as microcalcifications appear slightly blurred in the direction perpendicular to the direction of tube motion. In this project, a two-dimensional SAA method was developed to correct for this phenomenon. Shift amounts for every pixel location on each reconstruction plane were computed, taking into account the 2D arc projection location of reconstructed objects in each plane. Bilinear interpolation was used for partial pixel locations. Impulses at different 3-D locations were simulated and a few human subject tomosynthesis sequences were acquired for investigation. **Results:** Two-dimensional SAA demonstrated the improvement in the direction that is perpendicular to the tube motion direction. For human subjects, the appearance of calcifications from 2D SAA was sharper than traditional SAA at the direction orthogonal to the tube motion direction. The out-of-plane artifacts of calcifications changed from curved to be straight. **Conclusion:** Two-dimensional SAA is an effective method to reconstruct 3D tomosynthesis images of the breast. Compared with the traditional SAA, the new method corrects for 2D shift amounts coming from the isocentric tube motion. This provides more accurate and reliable results compared with other SAA algorithms. **Conflict of Interest:** Research sponsored in part by a research grant from Siemens Medical Solutions.

SU-FF-I-22

Analysis of Residual Geometric Artifacts From 4DCT

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Purpose: 4DCT has been shown to provide improved imaging of the thoracic and abdominal region, reducing the temporal artifacts observed from traditional "free-breathing" helical CT methods. However, the reconstruction accuracy of a 4DCT exam is dependent on the reproducibility of a patient's respiratory cycle (amplitude, period). Variation of this respiratory can introduce residual geometric uncertainty in the resulting 4DCT data. This work examines the geometric uncertainties introduced in phase resorted 4DCT imaging arising from the variability of patient respiration, comparing computational simulation with phantom measurements. **Method and Materials:** Examples of residual 4DCT artifacts were obtained by scanning a moving phantom capable of reproducing patient respiratory motion along the patient superior-inferior and lateral axes. Motion of the phantom stage was driven by RPM signals recorded from actual patient 4DCT scans. Geometric dimensions of the target volumes scanned on the moving phantom were compared to phase reconstructed 4DCT target images. A new computational tool was developed to examine the continuous variation of patient respiration upon cine CT image reconstruction. This tool reproduces basic 4DCT acquisition, allowing variation of patient and scan parameters such as scan start time relative to the RPM signal, multi-slice CT dimensions, amplitude of patient respiration and target volume dimensions. **Results:** Variation of 4DCT target volume has been observed to be as great as 13% from measured values. Spherical phantoms have shown as much as 17% deviation from the known value when compared to 4DCT reconstructed images. **Conclusion:** While 4DCT provides superior reconstruction of respiratory motion, it is not completely free from artifacts. A complete understanding of residual motion artifacts from 4DCT imaging is necessary before incorporating this data into patient treatment planning, especially with respect to techniques involving mid-phase (between exhale and inhale) images where the motion artifacts are most significant.

SU-FF-I-23

Comparision of Amplitude-Based and Phased-Based Binning Techniques for Respiratory Correlated CT

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Purpose: To evaluate amplitude-based and phase-based approaches for generating respiratory correlated CT (RCCT) images in terms of spatial coherence and residual motion artifacts. **Method and Materials:** A programmable robot arm (Kawasaki, FS-2, KRI, Wixom, MI) with an attached phantom consisting of 3 – 6 cm. diameter spheres was used to simulate various breathing patterns. Both the Varian RPM system and a bellows device were used as surrogates for monitoring. The robot arm was commanded to perform asymmetric "exhale/inhale" sequences with a variable cycle time, and it allowed for multi-axis trajectories, hysteresis and pseudo-random motion. The effectiveness of amplitude-based and phase-based binning algorithms on the resultant images of a spherical phantom was quantified by calculating the average deviation from a spherical surface. Both binning methods were applied to patient data sets and qualitatively evaluated. **Results:** Amplitude-based binning produces fewer artifacts, especially when the breathing frequency was varied during the acquisition. When using phase-based techniques the measured radii of spherical objects had twice the variance as compared to amplitude-based algorithms. **Conclusion:** Amplitude-based binning has merit in generating RCCT image volumes. Preliminary results suggest that they generate fewer artifacts and are more accurately correlated to the internal organ motion, especially when the breathing frequency varied during the acquisition. More investigation is warranted to evaluate the impact of this new methodology on treatment planning and delivery. **Conflict of Interest:** The author is an employee of Philips Medical Systems

SU-FF-I-24

Evaluation of Time Sampling and Its Interpolation Effect Based On Deconvolution Technique for Quantification of Cerebral Perfusion by Dynamic Contrast Enhanced CT

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Purpose: To investigate time sampling and its interpolation effect on cerebral perfusion measurements for proving the possibility of low-radiation-dose CT examination than usual. **Method and Materials:** Immediately after non-enhanced transverse scanning of a patient's brain, contrast material-enhanced scanning was performed every 1 second for 40 seconds at a single-slice level. Uniform time sampling was executed from 1/2 to 1/7 rate of total time series, respectively. Thirty tissue concentration time-course data were collected, and arterial input curve data were fitted by gamma-variate function. The sinc function was introduced for interpolation. Deconvolution analysis based on singular value decomposition was performed for quantification of CBF. The lowest singular value corresponding to the minimum difference between residue and its exponential curve-fitted function was considered as the optimal threshold value. The CBF values were calculated from the maximum of the scaled residue function. The perfusion values through time sampling and interpolation were compared with the original perfusion values by independent samples t-test. **Results:** The CBF values without interpolation were underestimated with a decrease of sampling rate, and with interpolation had a tendency fluctuated around the original CBF values. The CBV values through time sampling were not statistically different from the original CBV values regardless of the existence of interpolation. The MTT values without interpolation were overestimated with a decrease of sampling rate, and with interpolation had a tendency fluctuated inversely to CBF change around the original MTT. Time sampling without interpolation was statistically possible up to 1/2 sampling rate, and with interpolation up to 1/5 sampling rate. **Conclusion:** The perfusion values through time sampling with interpolation are acceptable up to some less sampling rate, and more accurate than without interpolation. This study will help in selecting reasonable image acquisition time interval for low-radiation-dose CT examination. **Conflict of Interest:** Young Investigator Competition

SU-FF-I-25

Optimizing Dose and Image Quality in Pediatric Computed Tomography

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Purpose: The goal of this work was to accurately quantify the doses delivered to pediatric patients during computed tomography (CT) exams while simultaneously evaluating the image quality of images obtained with the same protocols, and thus identify potential dose-saving protocols that maintain adequate image quality. **Method and Materials:** A tomographic newborn physical phantom was constructed from tissue-equivalent materials for use in evaluating the doses delivered to pediatric patients as a result of diagnostic imaging. Fiber optic-coupled (FOC) dosimeters were used along with the physical phantom to measure average organ doses during CT exams across a wide range of protocol parameters (80-120 kV, 50-150 mAs, 12 mm and 24 mm collimated beam widths, pitches of 0.75, 1.0, and 1.25, for both head and body protocols). Then, images of the Catphan CTP515 low contrast module were acquired using the same protocols, and scored automatically with a custom-written scoring routine with threshold contrast-to-noise ratios (CNR) based on radiologists' scoring of similar phantom images. **Results:** Measured effective dose values for head exams ranged from 0.33 mSv to 4.3 mSv, depending on protocol selection. These effective dose values are driven by doses to the bone marrow, bone surface, brain, and thyroid gland. Measured effective doses for CAP exams ranged from 1 mSv to 14.3 mSv, depending on protocol selection. A collimated beam width of 24 mm (16 x 1.5) was determined to be the optimal setting for both head and CAP imaging in terms of both image quality and dose. **Conclusions:** Tube potential and tube current-time product are the two major contributors to both dose and image quality. However, the use of pitch values less than 1.0 does involve a substantial dose penalty (approximately 30 percent greater dose) without providing any significant gains in image quality for general imaging tasks.

SU-FF-I-26

Tissue Equivalent Phantoms for the Evaluation of Tube Current Modulated CT Dose and Image Quality

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Purpose: To develop and test new, flexible, tissue-equivalent phantoms for the evaluation of tube current modulation dose reduction and image quality in CT. The developed phantom material also has applications for mammographic and 4-D time varying phantoms. **Method and Materials:** A compressible, flexible, urethane-based tissue equivalent phantom material was developed and utilized in the production of ellipsoid shaped phantoms for CT imaging. Multiple phantoms were created, each with different major (26-40 cm) and minor (18-28 cm) axes, in order to model patients of varying dimensions and thicknesses. All phantoms were made to be integrated with a Catphan CT image quality phantom as well as CTDI dose assessment phantoms. Image evaluation software was utilized in order to evaluate several image quality parameters in CT images taken using the phantoms in order to quantify the effects of tube current modulation in CT scanners for varying techniques. Ion chamber and gated fiber optically coupled dosimeters were also used with the phantoms in order to evaluate the effects of tube current modulation on dose to patients of varying dimensions. **Results:** It was found that the use of ellipsoid shaped phantoms allowed for more accurate observation of dose and image quality effects of tube current modulation in CT scanners over traditional circular acrylic phantoms. Patient doses were found the be less for studies in which tube current modulation was in use as compared to standard CT techniques, however the degree of dose reduction was found to be largely influenced by the major and minor axes of the ellipse. **Conclusion:** This work shows potential of ellipsoid phantoms to aid in dose reduction in CT scanning through tube current modulation by allowing more accurate modeling of actual patient dimensions.

SU-FF-I-27

CT Urography Radiation Dose Using Automatic Exposure Control

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Purpose: To measure and compare patient radiation doses during CT urography with automatic exposure control (both angular and z-axis tube current modulation) to patient radiation doses without automatic exposure control (tube current modulation alone), and to correlate these doses with corresponding image noise measurements. **Method and Materials:** Skin doses were measured by exposing thermoluminescent dosimeters placed on the abdomen (AP) and side (lateral position) of 18 patients examined with CT urography consisting of automatic exposure control (CARE Dose 4D group), and 20 different patients examined with angular tube current modulation only (CARE Dose group). Mean and standard deviation of patient skin doses were calculated. The CT urography protocol included three volumetric acquisitions of the abdomen and pelvis. Effective doses were calculated and used to compare radiation risk between the two patient groups. The variation in effective dose with patient size was also evaluated. Image noise was evaluated by calculating the standard deviation of pixel values from a region of interest in patient liver images. **Results:** The mean skin dose for CARE Dose 4D patients (63.4 ± 16.4 mGy) was 14.2% higher than that of CARE Dose patients (54.4 ± 7.39 mGy). The mean effective dose for CARE Dose 4D patients (10.6 ± 2.3 mSv) was 17.1% higher than that of CARE Dose patients (8.8 ± 1.8 mSv). Image noise increased with increasing patient size, however the increase was less for patients exposed with automatic exposure control. **Conclusion:** Patient effective dose, and thus radiation risk was 17.1% higher for CT urography patients examined with automatic exposure control compared to those examined with tube current modulation alone. Using automatic exposure control techniques in CT may be useful in reducing dose in small patients, however, for large patients the dose may actually increase to compensate for the increase in image noise.

SU-FF-I-28

A Critical Look at the Numerical Coefficients in CTDIVOL

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Purpose: To critically examine the assumptions leading to the formula for $CTDI_{VOL}$, which uses measured CTDI values at the center and periphery to estimate the overall average dose to a homogeneous cylindrical phantom. **Method and Materials:** $CTDI_{VOL}$ is a widely used figure of merit that estimates the average dose delivered by a CT scan to standard homogeneous cylindrical cylinders and offers a means of comparing doses delivered by different machines, or by the same machine using different scanning parameters. The calculation of $CTDI_{VOL}$ requires the measurement of two CTDI values: $CTDI_E$ measured at the edge of the cylinder and $CTDI_C$ measured at the center. $CTDI_{VOL} = (a \bullet CTDI_E + b \bullet CTDI_C)/\text{Pitch}$. The following three assumptions are made in order to determine a and b: 1): The phantom is a homogeneous cylinder positioned coaxially with the gantry. 2) The cylinder is exposed to a constant beam of radiation during the rotation of the gantry. 3) At any one instant during the scanner's rotation, the radiation density within the cylinder varies smoothly with position. Following a 360º rotation, assumptions 1 - 3 imply that the dose distribution is also cylindrically symmetric, smoothly varying, and at an extremum at the center. **Results:** The simplest result following from assumptions 1 - 3 is that $a = b = 1/2$. These do *not* agree with the values of a and b (2/3 and 1/3, respectively) that are used conventionally; these conventional values have the unphysical implication that the dose gradient at the center is discontinuous. **Conclusion:** $CTDI_{VOL}$, as it is currently calculated, underestimates the relative contribution made by the central CTDI value to the average dose, leading to a significant systematic error in a number used by regulatory and accreditation agencies. Equal weighting provides a more accurate value and should be employed.

SU-FF-I-29

Investigation of the Perspecta Display for 4D Visualization

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Purpose: Recent advancements in radiologic imaging (IGRT) have acquired 4D anatomic data permitting characterization of organ motion towards improving radiotherapy delivery. For radiation oncology patients, images illustrating temporal migration or tumor motion as a result of innate biological function can provide significant benefit towards improving target accuracy and minimizing healthy tissue dose. This study examines the utility of the Perspecta Spatial 3D system (Actuality Systems Inc) to display dynamic 3D data in comparison to flat panel 2D displays. **Method and Materials:** The AqSim (Philips Medical Systems) CT scanner was used to obtain scans of a patient with lung cancer, and entered into the Pinnacle[3] treatment planning system (Philips Medical Systems). A clearly delineated lung tumor was contoured in each pertinent CT slice. Ten scans (64 slices each) were obtained during the breathing cycle. Data were viewed side-by-side on a flat panel display and the Perspecta 3D system for comparison. **Results:** The Perspecta display permitted simultaneous visualization of ten CT scans at ~ 1 Hz per dataset which was similar to the natural breathing rate during image acquisition. Optimal static beam orientation for dynamic target coverage and OAR avoidance was more easily accomplished on the Perspecta than on the 2D display. **Conclusion:** The 3D Perspecta display successfully depicted anatomic motion, clearly indicating tumor and OAR motion. In comparison to the 2D flat panel display, the Perspecta display permitted the radiation oncology team to readily visualize the temporal nature of lung tumor location for consideration during treatment planning. This application could play an important role in defining and displaying 4D patient data, which was previously relegated to predominantly 2D RTP systems. Furthermore, breath-hold and coached breathing techniques may be quantitatively evaluated using this method. **Conflict of Interest Statement:** Actuality Systems Inc. provided the 3D display used in this study.

SU-FF-I-30

Dose Indices of Radiation to Skin in Invasive Cardiology Procedures

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Purpose: Tissue injury depends on the extent as well as the intensity of the assault. It would be helpful to develop skin dose indices that are more descriptive of the skin area receiving radiation above a threshold value of potential injury. **Method and Materials:** For quality control, a GafChromic XR Type R film was placed close to the skin of 36 patients undergoing cardiac catheterization procedures. A hand-held densitometer was used to measure the peak radiation dose. With the approval of the Institutional Review Board, these films were scanned. Contours were drawn at the increment of 100 cGy. Using each contour value as a threshold, the area exceeding this threshold, and the average dose within this area were computed. **Results:** For 3 patients who had skin dose exceeding the 200 cGy threshold, but less than 300 cGy, the total area of the skin with this amount of irradiation ranged from 1 cm^2 to 27 cm^2. The averages doses within these areas were not greater than 221 cGy. One patient had incurred a peak entrance dose of 409 cGy. For this patient, the area exceeding 300 cGy was 82 cm^2 and the area exceeding 400 cGy was 4 cm^2. The limited skin areas associated with the high skin entrance radiation exposures might explain the lack of significant skin injury in this sample of patients. **Conclusion:** If we define "skin dose $load_{threshold}$" to be the area exceeding a chosen threshold value, the skin dose $load_{200}$ would be the area exceeding 200 cGy and having the potential of skin injury. Summary statistics describing the dose distribution within this area might also be helpful. An example parameter would be the average dose within the area described by the "skin dose $load_{threshold}$". This investigation has demonstrated the technical feasibility of providing such dose indices.

SU-FF-I-31

Diagnostic Utility Evaluation of a ASi:H/CsI(Tl) Flat-Panel Based Digital Radiography System

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Rationale and objectives: The aim of this work is to quantitatively evaluate the diagnostic utility of our digital radiography system based on a aSi:H/CsI(Tl) flat-panel. **Materials and Methods:** Two commercially available amorphous silicon flat-panel imaging systems are tested together using a chest phantom. This phantom contains the low contrast objects in the lung, heart and subdiaphragm regions, and the spatial resolution pattern in the lung region. Digital chest phantom images are acquired under the same environment, e.g., exposure condition, a focal spot, and a source-to-

image receptor distance and a stationary antiscatter grid. All images are post-processed by each image processing unit. **Results:** The signal-to-noise ratio(SNR) of the nine low contrast objects in three chest regions and the spatial resolution are analyzed. No significant difference is showed in three different image processing units based on the same detector. **Conclusions:** The resulting SNRs are in the range of Rose Model for human observers to detect a contrast object signal. Finally, the simple procedure employed in this work eliminates observer subjectivity and can be applied for the detectability measurement of low contrast objects in other digital diagnostic modalities.

SU-FF-I-32

Performance and Stability of the Varian Cone-Beam CT System

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Purpose: A cone-beam CT (CBCT) system was implemented on a Varian Trilogy linac in our department in May 2005. Weekly CBCT quality assurance has been performed. The purpose of this work is to present clinical CBCT performance and determine parameters that are predictive of reduced performance. **Method and Materials:** From July 2005 to February 2006, a quality assurance program was conducted on a weekly basis to include both image quality and geometrical characteristics of the system. Cone-beam CT software version 1.2 was used during this study. Both large scan volume 'half-fan' and small scan volume 'full-fan' CBCT scans were included for analysis. Parameters checked as part of our quality assurance procedures were: constancy of Hounsfield units (HU) for different materials, image uniformity, high contrast spatial resolution, low contrast resolution, and spatial linearity. Data was analyzed globally using the descriptive statistics of mean and range to give an overall statement of CBCT performance and was analyzed in a time-ordered fashion using process behavior charts to identify predictive parameters. **Results:** Geometrical accuracy was within 1 mm for both scan types and was reproducible throughout the study period. The average and (minimum, maximum) data for image uniformity, average HU difference for 7 materials, and high contrast spatial resolution were as follows: large scan volume; 73.7 HU (-21.2, 103.8), 0 HU (-32, 39), 0.55 mm (0.45, 0.63) and for small scan volume; 92.1 HU (49.7, 116.1), -1 HU (-32, 26), 0.48 mm (0.45, 0.56). For image uniformity, action levels by time-ordered process behavior analysis were identified. **Conclusion:** Apart from a single data point, the Varian CBCT system was stable over the study period. Image uniformity was predictive for a mis-performing CBCT system.

SU-FF-I-33

A Graphical and Quantitative Procedure for Amplitude-Gated Treatment Planned Using Phase-Based 4DCT Using the Varian RPM System

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Purpose: A graphical and quantitative procedure for amplitude-gated treatment planned using phase based 4DCT of free breathing patients using the Varian RPM gating system has been developed as a part of the study of phase and amplitude based imaging and treatment. There are several phase-based CT scanning systems that produce phase-based images for gated treatments, but for free breathing phase may not be a reliable predictor of tumor location. Good correlation has been shown between abdomen height and diaphragm position, making it a promising treatment modality. **Method and Materials:** A phase-based retrospective CT scan from a Philips large bore 16 slice CT scanner is obtained and the phase markers are adjusted to delineate actual breaths. A gating window that is a subset of the whole CT scan is set and a visual representation of gated motion called a MIP(maximum intensity projection) is created to visualize any anatomical excursions. The Varian RPM data is then compared with the scan data to quantify the actual marker block motion(or chest height) during the gating window as well as for an entire phase. The scan data is then presented not only as a percentage of an average breath, but as a chest height range within the total. This information is checked on treatment days and adjusted if necessary. The gating signal and fluoroscopy are compared to a 4D DRR generated from the MIP to check for geographic as well as systematic misses. Before treatment a gated port film (gated over several breaths and dose limited) can be captured to verify gating of the treatment beam. **Results:** For phantom based studies of regular breathing the method is robust. The model converts phase to amplitude of abdomen height. **Conclusion:** This method can validate a gated treatment using different imaging modalities.

SU-FF-I-34

How Well Do Ctdi Data Obtained in a Body Phantom Predict Patient and Embryo Doses in Abdominal Ct?

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Purpose: In this work, we compare central dose measurements in anthropomorphic phantoms with corresponding Computed Tomography Dose Index (CTDI) values obtained at the center of the body CTDI phantom. **Method and Materials:** An adult Rando phantom was used to determine patient/fetal dose during an abdominal/pelvic CT examination acquired with clinically relevant techniques. TLD's were placed in multiple locations in the phantom to measure the dose in the abdomen/pelvis region. The corresponding $CTDI_{FDA}$ and $CTDI_{100}$ values were determined using an ionization chamber placed at the center of a 32 cm diameter acrylic dosimetry phantom. **Results:** A pregnant patient, whose size is comparable to the Rando phantom, undergoing a CT examination on a commercial scanner receives an embryo dose of 16 mGy/100mAs, whereas published CTDI values for this scanner are *lower* by factor of 2.9 to 4.0. This large discrepancy can be accounted for by the following three factors: (a) specification of a tissue dose, as opposed to an air or acrylic dose; (b) use of a realistic phantom size; (c) inclusion of the total x-ray scatter in the tails of CT dose profiles. **Conclusion:** To obtain accurate body patient doses from any specified body CTDI data, it is essential that soft tissue doses be obtained rather than air/acrylic doses, and with appropriate correction factors that account for the scan length and for the size of the patient.

SU-FF-I-35

Do Lead Aprons Reduce Patient CT Doses?

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Purpose: Hitherto, the Radiology community has assumed that scatter radiation in CT originates within the patient, and that any use of lead aprons would have no measurable effect on patient (scatter) doses. In this study, we investigated the validity of this assumption, and quantified the potential for reducing patient (scatter) doses in CT when lead aprons are placed adjacent to the directly irradiated region. **Method:** Thermoluminscent dosimeters (TLDs) were used to measure dose distributions in three anthropomorphic phantoms (newborn, 10-year old, and adult male). Phantoms were scanned on a 4-slice GE Lightspeed CT scanner using 140 kV, 900 mAs, and contiguous axial scanning. We performed a chest CT scan of each phantom with approximately 45 TLDs distributed through the directly irradiated chest region, and distal regions (head and abdomen). A second CT was also performed with the head and abdomen regions wrapped with a 0.5 mm equivalent lead apron. We estimated the effect of the lead apron on regional doses, as well as the change in total energy absorbed. **Results:** As expected, the addition of a lead apron had no effect on doses in the directly irradiated chest region. The addition of a lead apron reduced head doses by about 40%, and abdominal doses by about 25%. However, the scatter radiation in the "head" accounts for ~3% of the total energy imparted to the patient, and the corresponding value for the abdomen is ~7%. As a result, the reduction in total energy imparted to the patient from the introduction of lead aprons was only ~5%. **Conclusions:** Our results show that lead aprons reduce patient doses from "external scatter" by about 5%. The origin of "external scatter" in CT merits additional study.

SU-FF-I-36

Use of Tissue Air Ratios to Obtain Organ Doses in CT

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Purpose. To develop a practical method for obtaining organ doses in CT. **Method.** We measured tissue air ratios (TAR) as the ratio of the air kerma at a specified location in an anthropomorphic phantom to the corresponding

iso-center free-in-air kerma. Measurements were obtained using a pitch ratio of 1, identical radiographic techniques (kV/mAs), and a scan length to ensure the full contribution from scattered radiation. TAR values were measured at selected head and body locations in a Rando phantom on a GE LightSpeed CT scanner operated at 80 and 120 kV. **Results.** The average iso-center free-in-air kerma for modern CT scanners operating at 120 kV is 0.25 ± 0.05 mGy/mAs for head imaging, and 0.23 ± 0.08 for body imaging. At 120 kV, the average TAR value in the head of a Rando phantom was ~0.70 and the average body TAR ratios was ~0.64. Head TAR values showed only minor spatial variations, whereas body TAR ratios were highest on the anterior surface and lowest at the lateral chest surface and the abdomen center. The average ratio of TAR values at 120 kV to those at 80 kV was 1.28. **Conclusions.** TAR offer a direct method for obtaining organ doses in CT, and can be readily measured for any CT scanner or patient size. Modern CT scanners operated at 120 kV have result in tissue doses in the directly irradiated region of ~0.19 mGy/mAs for head examinations and ~0.16 mGy/mAs for body examinations.

SU-FF-I-37

A Comparison of Full-Field Digital and Screen-Film Mammography Dose

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Purpose: To determine whether mammograms acquired with a full-field digital mammography (FFDM) unit using automatic exposure control (AEC) reduce patient radiation dose and exposure time as compared to screen-film mammograms. **Method and Materials:** Exposure techniques and mean glandular dose (MGD) for FFDM and screen-film mammography was compared for breast tissue equivalent attenuation slabs of varying thickness (2-8 cm) and glandular content (0-100%). FFDM images were acquired with a Lorad Selenia unit with AEC set to the manufacturer's recommended levels. Screen-film mammograms were acquired with a Lorad M-IV unit and Kodak Min-R 2000 screen-film system with AEC adjusted for an ACR accreditation phantom optical density of 1.8 OD. In addition, a patient survey including 150 mammograms compared the FFDM exposure techniques and MGD with the patient's corresponding screen-film mammogram acquired 1 year prior. A 50% glandular tissue content was assumed. **Results:** For breast tissue equivalent attenuation slabs 4 cm thick or more, FFDM AEC was found to call for higher x-ray beam energy exposures than screen-film, resulting in lower MGD (mean 40%) and exposure time (mean 50%). Below 4 cm, FFDM kVp was lower than screen-film, causing higher MGD (mean 15%) and exposure time (mean 20%). For the patient survey, FFDM resulted in a significantly lower MGD (mean 35%) and exposure time (mean 52%) than the corresponding screen-film mammogram. Similar to the attenuation slabs, the FFDM dose and exposure time were generally higher than screen-film for 2-4 cm compressed breast thickness and lower than screen-film for 4 cm and above. **Conclusion:** FFDM using manufacturer's recommended dose settings results in significant dose reduction as compared to screen-film mammography, particularly for 4 cm compressed breast thickness and above.

SU-FF-I-38

Calibration of An ASi Electronic Portal Imaging Device for Dosimetric Evaluation of Intensity Modulated Radiation Therapy

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Purpose: To calibrate an amorphous Silicon (aSi) Electronic Portal Imaging Device (EPID) for dosimetric evaluation of Intensity Modulated Radiation Therapy (IMRT). **Methods and Materials:** This study was performed using a 6 MV photon beam of a Primus linear accelerator with an aSi EPID. A water-filled penta step-phantom of perspex was fabricated for calibrating the EPID. Absolute dosimetry was performed using a calibrated 0.14 cc ion chamber. A polystyrene slab with 21 bores (each separated by 1 cm) to accommodate the ion chamber was used for measuring dose below each step of the phantom. The EPID was calibrated at a source to detector distance of 150 cm. The calibration procedure involved: i) Acquisition of Electronic Portal Images (EPIs) with the centre of the step-phantom positioned at isocentre for 1, 2 and 3 monitoring unit settings. ii) Measurement of the dose profile below the step-phantom with the ion chamber placed at pre-determined positions on the polystyrene slab iii) Acquisition of an EPI with the centre of the step-phantom at isocentre and the polystyrene slab fixed onto the surface of the flat panel detector. This was used to locate the positions of the ion chamber with respect to the step-phantom. iv) Plotting the calibration graph for pixel values (averaged over ROI of 10 x 12 pixels) and dose. EPIs of IMRT segments were acquired with the EPID in the 'port-during' mode for each field. All the individually acquired segments were added using codes developed in MATLAB (version 6.5) to get the fluence map. **Results:** The pixel values of the EPIs were found to increase linearly with dose. The fluence maps acquired using the calibrated EPID were verified with the planned fluence maps. **Conclusion:** Therefore it is concluded that EPID could be used as a dosimetric verification tool for IMRT.

SU-FF-I-39

Estimating Conversion Coefficient of KERMA Free in Air to Glandular Dose in Mammography: A Comparison Between BR12 Model and a Realistic Voxel Model

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Purpose: To compare conversion coefficient of KERMA free in air to glandular dose, in mammography, simulated to BR12 model and a realistic breast voxel model. **Method and Materials:** We simulate the glandular dose (D_g) and KERMA free in air (K_{ai}), using the Monte Carlo program MCNP (version 4B) to estimate the conversion coefficient (c_g) of KERMA free in air at entrance skin in glandular dose. The computational universe generated to simulate a mammographic procedure mimics LORAD III mammographic equipment. The focal spot of molybdenum irradiates photons isotropically in a solid angle of 16.8°. The bucky is 0.6190 m far from de focal spot. Above the model there is a PMMA compress paddle 0.002 m thicker. The add filtration (30 μm Mo thicker and 25 μm Rh thicker) was located at 0.050 m far from the focal spot. Tow spectra were used in voxel model simulations: 28 kVp with Mo add filtration and 30 kVp with Rh add filtration. **Results:** The c_g presented on Mo/Rh simulation was 1.5 times larger than the presented on Mo/Mo simulation. Comparing the voxel model to the BR12 model we have actually a super estimation on both simulated c_g values: 3.4 times considering the simulation with Mo/Mo target/filter combination, and 2.4 times considering the simulation with Mo/Rh target/filter combination. **Conclusion:** The c_g values show a decrease of 58.7% considering the Mo/Rh target/filter combination and a decrease of 70.2% considering the Mo/Mo target/filter combination, to the realistic breast model as comparative pattern. These variation on c_g are probably caused by the definition of a non-anthropomorphic model composed by an homogeneous distribution of tissues as pattern, that makes unviable the observation of the absorbed energy by each tissue; and because this model do not consider the position of glandular tissue in the real breast geometry.

SU-FF-I-40

Evaluation of Different Ways to Describe An X-Ray Spectrum and the Implications in the Absorbed Energy in a Head Voxel Model

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Purpose: To evaluate the behavior in absorbed energy due by approximation in irradiation energy spectra description to Monte Carlo simulation. **Method and Materials:** A head voxel model was coupled to GEANT4.7 program to obtain the absorbed energy distribution in anatomical structures of the model. Three simulations were realized, using an x-ray beam parallel to the left side of the model, with an isotropic beam distribution. First the energy beam was defined according to "Catalogue of Diagnostic X-ray Spectra and Other Data", using 70.0 kVp of tube tension, with 17° target angle, W as target material, without ripple and with 1.0 mm Al of add filtration. After that the beam was defined as monoenergetic at 30.5 keV, representing the mean energy of the cataloged spectrum. Other monoenergetic beam of 29.5 keV was used, representing the first HVL energy according the catalogued spectrum. **Results:** The simulation using the catalogued spectrum was defined as reference. The simulation, using the 30.5 keV monoenergetic beam, shows twenty structures (71%) with differences larger than 10%, when compared to the reference data, including five structures (18%) that presented differences upper than 20%. In the simulation using monoenergetic beam corresponding to the first HVL energy, fourteen structures (50%) presented

differences larger that 10%, compared to the reference data, including four structures (14%) showing differences upper than 20%. To both simulations total absorbed energy showed difference down to 7%, compared to the reference. **Conclusion:** The absorbed energy is dependent on the x-ray spectra description; it means that the configurations of the spectra (photon flux, mean energy and HVL energy) significantly interfere in absorbed energy distribution. This kind of approximation must be avoided, when we try to describe the absorbed energy accurately, especially in simulations used in radiological protection applied to radiological area.

SU-FF-I-41

A Series of 4D Pediatric Hybrid Phantoms Developed From the UF Series B Tomographic Phantoms

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Purpose: To develop a series of the pediatric hybrid computational phantoms based on the non-uniform rational B-spline (NURBS) technology by converting the existing series of UF pediatric tomographic phantoms. **Method and Material:** The series of UF tomographic phantoms, newborn female, 9-month male, 4-year female, 8-year female, 11-year male, 14-year male, which were developed by the researchers at University of Florida, were employed for this study. The tomographic phantoms were imported to the 3D-DOCTOR (Able Software Corp., Lexington, MA) segmentation and 3D rendering software, and polygon mesh models representing internal organs and body contour were generated. The polygon mesh models were imported to the Rhinoceros software (McNeel, Seattle, WA) based on NURBS-technology, and Smooth NURBS surfaces were developed for organ and tissue contours, and the NURBS-based organ models were generated organ-by-organ. The NURBS organ models were integrated into hybrid human phantoms by the Rhinoceros software. **Results:** A total of 6 hybrid human phantoms were developed from the existing 6 UF tomographic phantoms. The cube-shaped organ contours in the tomographic phantoms were innovatively smoothed in the resulting hybrid phantoms based on NURBS surfaces. The organ volumes calculated from tomographic and hybrid phantoms were in agreement within 5%. **Conclusion:** The resulting phantoms are deformable and can thus be used to represent 25^{th} or 75^{th} percentile subjects through the adjustment of control points surrounding each organ and body contour. The NURBS-based pediatric phantoms developed in this study can be imported into Monte Carlo calculation code, and broadly utilized for dosimetry calculation. The techniques developed in this study will be also applied to the development of NURBS-based 3D phantoms representing 50^{th} and other percentile adult male and female subjects for use in radiation protection applications, as well as occupational or medical exam dose reconstruction.

SU-FF-I-42

The Influence of Bowtie Filter Selection, Patient Size and Patient Centering On CT Dose and Image Noise

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Purpose: Bowtie filters have been used on CT scanners for many years to reduce patient dose. In this study we rigorously characterized bowtie filter dose and noise performance and discovered some significant clinical implications for the CT scanner technologist. Methods and Materials: Various size and shape phantoms were scanned on a GE LightSpeed VCT scanner using each available bowtie filter with phantoms positioned at 0 mm, 30 mm and 60 mm below isocenter. Surface and CTDI doses were measured along with image noise. Relationships for dose and noise were determined using regression methods and compared to computer simulated results. An algorithm was developed to determine the centering error from scout scans and subsequently used to evaluate the clinical implications for 273 adult body patients. **Results:** The measured noise and dose performance agreed with simulations and indicated an optimum bowtie filter can be selected as a function of phantom size. The 32cm CTDI phantom scanned on the large, medium and small bowtie filters produced a dose savings of 29%, 24%, and 17% respectively compared to the flat filter for similar image noise. However, the surface dose increased by 18% and 41% for the miscentered cases while image noise increased by 2% and 13% with the optimum CTDI phantom bowtie. The noise increased even more (5% and 20%) for a miscentered nominal body shaped phantom. The clinical scout scan analysis indicated that 54% of patients were miscentered by 20 mm to 60 mm. With this miscentering, the surface dose penalty for the 32 cm CTDI phantom would range from 22 % to 71% assuming mAs is also increased to compensate for noise,. **Conclusions:** Clinical image quality and dose efficiency can be significantly improved on scanners with bowtie filters if technologists can nominally center the patient region to be scanned.

SU-FF-I-43

Air-Kerma Length Calibration of CT Ionization Chambers

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Purpose: To develop a slit-based calibration method, for the quantity air-kerma length, for CT ionization chambers which combines the radiation response and response length properties of the chamber. **Method and Materials:** CT ionization chamber response profiles are measured for 3 models, and the response length is calculated. Air-kerma length calibration coefficients require a correction for radiation that is scattered from and transmitted through the aperture. The Monte Carlo transport code MCNP5 is used to generate this correction factor, C_{st}. A variable-width aperture is used to test a previously published, linear-regression based correction factor, C_{reg}. **Results:** The response lengths of several CT ionization chambers are calculated based on the chamber's response profile. The response lengths vary between 9.9cm and 12.1cm, which results in errors of -20% to +1%. The C_{st} correction factor yields an air-kerma length calibration coefficient that varies by 0.1% for aperture widths ranging from 5mm to 90mm. C_{reg} yields air-kerma length calibration coefficients that vary by 1% over the same range of slit width. **Conclusion:** The proper way to calibrate a CT ionization chamber is via air-kerma length calibration, which combines the radiation response and response length in the calibration coefficient. Currently CT ionization chambers are calibrated with a large x-ray field that exposes the entire collecting volume, which only characterizes the radiation response of the chamber. The response length is then assumed to be 10cm, which is not always true and can cause errors of up to 20% compared to using an air-kerma length calibration coefficient.

SU-FF-I-44

Management of Patient Radiation Dose in Interventional Fluoroscopy

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Purpose: Some complex interventional procedures require significant amounts of radiation for their completion. In 2006 JCAHO added a 15Gy single field fluoroscopic skin dose to the list of sentinel events. An active radiation management program contributes to optimization of the patient's benefit/risk ratio. **Method and Materials:** Periodic equipment quality testing and calibration. Patient radiation history to determine the quantity and location of previous significant radiation events Appropriate patient consent Operator and staff dose management during the procedure Documentation and clinical follow-up when significant doses of radiation are used Continuing clinical follow-up when deterministic injuries are suspected or observed **Results:** Our program was implemented in June 2005. Significant issues include acquisition of the patient's radiation history, active management of dose rate by operators during procedures, and complete documentation at the end of each procedure. Post procedural patient discussions and integrating radiation follow-up into our standard 30 day post-intervention telephone call were easy. The initial trigger level for immediate justification of significant radiation usage and patent follow up was 3 Gy cumulative dose at the IEC interventional reference point. In January 2006 and after consultation with the institutional radiation safety committee, the trigger was raised to 5 Gy (corresponding to a peak skin dose in the range 2 -3 Gy for most procedures). Special rules apply to patients with unusual or multiple procedures. **Conclusion:** The world-wide occurrence of a major deterministic injury is estimated to be one or two orders of magnitude less frequent than death from an interventional procedure. Simple technical improvements such as better dose displays, low-dose-rate defaults, and automated data collection would be helpful. With these, operators and monitoring nurses can more easily maintain a

level of dose awareness during a procedure appropriate to an ongoing benefit/risk analysis.

SU-FF-I-45

Labview Graphical User Interface for Micro Angio-Fluoroscopic High Resolution Detector

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Purpose: A graphical user interface based on LabView software was developed to control a Micro Angio-Fluoroscopic detector (MAF) for real-time acquisition, display and rapid frame transfer of high resolution images of a region-of-interest. **Method and Materials:** A MAF detector was built by our group using a CsI(Tl) phosphor, fiber-optic taper and Light Amplifier optically coupled to a progressive scan charged coupled device (CCD) camera which provides real-time 12 bit, 1k x 1k images. During image acquisition, the MAF detector is inserted in the x-ray beam of an angiographic unit, between the x-ray image intensifier and the patient. Images can be captured in continuous or triggered mode and the camera can be programmed by a computer using the serial communication. A graphical user interface was developed to control the camera modes such as gain and pixel binning as well as to acquire, store, display, and process the images. **Results:** The program, written in LabView, has the following capabilities: camera initialization, synchronized image acquisition with the x-ray pulses, flat field correction, window and level adjustment, brightness and contrast control, and looped play-back of the acquired images. Acquisition starts when the first triggering pulse is read by the interface. The acquired sequence of images is automatically displayed in a loop after completion of acquisition and the images can be stored or deleted at the user's discretion. Frame rates can be up to 30fps in 2x2 binning mode and 25fps unbinned. **Conclusion:** The user friendly implementation of the interface along with the high frame rate acquisition and display for this unique high resolution detector may provide angiographers a new capability for visualizing details of small endovascular devices such as stents and hence enable more accurate image guided localization. (Support: NIH Grants R01NS43924, R01EB002873)

SU-FF-I-46

Acceptance Testing and Verification of Automatic Brightness Control Logic of A Fluoroscopic System

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Purpose: To verify the functionality and operation of fluoroscopic automatic brightness control employed in a modern cardiovascular angiography system, equipped with flat panel detector, as part of an acceptance testing of a new installation, and to obtain the fluoroscopic "patient" entrance exposure (air kerma) for reference information. **Method and Materials:** A Siemens AXIOM Artis angiography system was acceptance tested under a fixed geometric arrangement. The PMMA phantom was employed to simulate the patient thickness varying from 0.635 cm (¼" nominal) to 35.56 cm (14" nominal) in increments of 0.635 cm. The fluoroscopic imaging parameters; "kVp", "mA", "pulse width", "spectral shaping filter; copper filters", " half value layer; HVL", "patient air kerma; PAK", and "flat panel input air kerma; FPIAK" were recorded as the phantom thickness was increased. Upon completion of the data acquisition, the imaging parameters were plotted against the phantom thickness. The graphs were then analyzed, and compared with a typical preprogrammed fluoroscopy operation curve supplied by the manufacturer. **Results:** The primary variable of this fluoroscopy system is the tube potential in conjunction with the spectral shaping filter selection. Depending on the Flat Panel Detector Signal (FPDS) level, the tube current and the pulse width are varied until the predefined FPDS level is achieved. The graphs show the operation logic indeed followed the preprogrammed logic and the PAK increased exponentially, ranging from 0.2 mGy/min to 100 mGy/min, while the FPIAK was maintained at a constant level of 0.7 to 0.8 μGy/sec. **Conclusion:** Due to the extensive use of spectral shaping filters and the sophisticated fluoroscopic operation logic design, the fluoroscopic tube potential is kept at optimum levels to provide good image quality by ensure high image contrast and proper penetration for a wide range of patient (PMMA) thickness. The graphs confirmed and verified that the system "behaved" as designed.

SU-FF-I-47

A Method of the Pixelized Detectors Coordinate Resolution and MTF Estimation

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Purpose: We propose a simple method to estimate MTF and coordinate resolution of pixelized detectors used in digital imaging systems. **Method and Materials:** The traditional determination of coordinate resolution for pixelized detectors is mainly based on the use of line spread function measurements. The proposed method is based on the determination of the statistical correlation between neighbour elements in the detector. The correlation is evaluated by means of statistical noise measurement of the isolated elements and the linear combination of neighbour elements. To suppress the possible contribution of the beam spatial variation, the difference between values of neighbour elements is used. The distribution of differences between the detector neighbour pixels is constructed for the pixels sharing an edge (either in X or Y directions), or having one common vertex (U or V). For the validation of the method, we have studied the GE Senographe 2000D mammography unit digital detector. The detector has been irradiated by X-rays across its entire surface. The dependence of the resolution on the photon intensity value and the pixel coordinate has been studied. The resolution function has been considered as a result of convolution of Gaussian and uniform distributions. **Results:** The coordinate resolution of the studied detector, having pixel size of 100 μ, is of the order of 50 -55 μ, that is, almost twice the value conditioned by pixel geometrical size. A small asymmetry between the X and Y directions has been detected. The reconstructed modulation transfer function agrees with MTF measurements of the studied detector, within a few percent. **Conclusion:** The proposed method can be useful for the estimation of coordinate resolution, line spread function and modulation transfer function of the detectors used in the systems of medical digital imaging.

SU-FF-I-48

Assessment of Detective Quantum Efficiency: Inter-Comparison of IEC 62220-1 with Representative Prior Methods

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Purpose: To evaluate a new international standard method for the measurement of detective quantum efficiency (DQE) of digital radiography systems in comparison with representative prior methods. **Methods and Materials:** Three DQE evaluation methods were considered: 1) a relatively recent international standard method published by the International Electrotechnical Commission (IEC, 62220-1, 2003) which was evaluated in comparison with previously published methods by 2) Dobbins *et al* (Med Phys 22:1581-1593, 1995) and 3) Samei *et al* (Med Phys 30: 608-622, 2003). In addition to an overall comparison of the methods, the impact of the defining factors that comprise each method were evaluated including: beam quality, the presence of beam-limiting devices (apertures or collimators), the NNPS analysis algorithm and processing parameters, and the MTF test device and associated analysis methodology. **Results:** The IEC DQE results at low/mid-frequencies were lower than those obtained using the method of Dobbins *et al* and Samei *et al* by 3.3% and 6.5%, respectively. Averaged over 1.5–2.5 mm^{-1}, the DQE estimate according to the IEC method was 7.1% lower and ~12.4% higher than that of the other two methods, respectively. The overall DQE methods of Dobbins *et al* and Samei *et al* agreed well (within 2.0%) in the low- to mid-frequency range but diverged by up to 10% at higher frequencies. Of the influencing factors on the DQE estimate considered, the most significant impact was seen with the MTF measurement method, followed by the beam-limitation method. **Conclusions:** Comparison of DQE estimates using the new standard technique with results using prior methods demonstrated that measurement method can impact the DQE estimate by as much as 12%. Specifically, the results suggest the use of beam limitation using internal collimation (rather than external apertures) and use of a radio-opaque edge MTF test device for more accurate estimation of the DQE.

SU-FF-I-49

Normalized Absolute Average Deviation: A New Method for Computing MR Image Uniformity

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Purpose: To evaluate the new Normalized Absolute Average deviation (NAAD) MR image uniformity metric that is in the new IEC MRI performance standard. NAAD is SNR insensitive and applicable to volume, surface and phased array coils, unlike the current standard peak difference (PD) NEMA uniformity method (formerly called the integral uniformity measure). **Method and Materials:** NAAD computes the average absolute deviation of each pixel within the measurement region of interest (MROI) from the mean of the MROI, normalized with respect to the MROI average. Data collected on a Philips Infinion 1.5T scanner (Highland Heights, OH) using a body coil transmitter, a quadrature head coil and a surface coil. Both NAAD and NEMA PD method uniformity computed. The head coil data was collected over a range of slice thicknesses and receiver bandwidths to vary the image SNR significantly and demonstrate NAAD SNR robustness. NAAD is demonstrated to work with a highly non-uniform surface coil by measuring a series of nested MROI, starting at the intense signal region near the coil and growing away to less intense signal regions. **Results:** By using all pixels within the MROI NAAD is less SNR sensitive than the PD NEMA method. As SNR varies within the MROI, NAAD results are essentially constant while PD results vary significantly. NAAD produces surface coil uniformity measurements that are more realistic than PD uniformity measurements. **Conclusion:** Our evaluation shows that NAAD is almost completely insensitive to SNR levels and can be used with all coils. This increased flexibility and robustness should be useful for the evaluating the new generation of surface coils optimized for MRI parallel imaging where coil spatial non-uniformities are used as a spatial encoding mechanism. **Conflict of Interest:** This work was supported by the authors' employers.

SU-FF-I-50

A Mechanical Alignment Method for Removing Moiré Pattern in Digital Radiography with a Carbon-Interspaced Grid

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Purpose: To remove moiré patterns of a carbon-interspaced X-ray anti-scatter grid in use with a digital radiographic detector by matching a grid line frequency with a DR sampling frequency. **Method and Materials:** A carbon interspaced grid with a line frequency a little higher than the sampling frequency of DR was processed by a sawing machine which was controlled as micro unit. An amorphous selenium DR panel was used in imaging. A motion-control jig was developed to change the disposition of the grid with respect to the detector pixels. An alignment process was divided into horizontal and vertical directions. The detector underneath of the X-ray grid was translated and rotated with the resolution of 2 microns and 0.01 degrees respectively so that the pattern lines were oriented perpendicular to a horizontal axis in an image plane. A height of the grid from the detector was varied by 4 micrometers to magnify the shades of the grid lines at the detector and, hence, to exactly match with the sampling frequency of the detector. **Results:** A moiré frequency was proportional to a difference between the grid shade frequency and the DR sampling frequency. An angular displacement of the detector caused a frequency difference to indicate a higher frequency of moiré. The horizontal translation did not change the moiré frequency but only phases. An impact of the phase shift on image became larger at lower frequency of moiré patterns. **Conclusion:** A Moiré pattern in the use of a fixed type of grid can be removed by matching a grid line frequency with a DR sampling frequency. High straightness and uniformity of grid lines of carbon-interspaced grids and micro-controlled alignment methods enable frequency matching to remove moiré patterns without a software filtering and a moving grid.

SU-FF-I-51

New Combined High-Resolution Region-Of-Interest Microangiographic Detector and Large Field of View Image Intensifier System: A Contrast-To-Noise Comparison

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Purpose: To demonstrate the advantage of combining a new high-resolution region-of-interest (ROI) microangiographic detector (MA) and a standard x-ray image intensifier (II), using contrast-to-noise ratios (CNR) of vessel phantoms within a scattering medium. Methods and Materials: The MA was mounted onto a Toshiba Infinix 3000 C-arm angiographic unit so that the user can switch between the MA and II during an intervention at any viewing angle. Projection images can be acquired at nearly identical geometry with either detector, allowing for accurate inter-comparisons. CNRs were measured for vessel phantoms (50-1000μm inner-diameter polyethylene tubing) filled with iodine-contrast agent and placed on a uniform head-equivalent phantom used to simulate the scatter and beam hardening effects of the head. Both detectors were operated with optimal exposure techniques (allowing the II system to choose the 'best' kVp and mAs settings and selecting an exposure (mAs) that provides a sufficiently high signal for the MA). The CNR provides a quantitative measure of object visibility in the image, and hence system performance. **Results:** Compared to the II, the MA provides consistently higher CNR for all vessel sizes, with an average improvement factor (CNR_{MA}/CNR_{II}) of 1.6. A clear trend is observed, with CNR improvement factors increasing with decreasing vessel diameter. **Conclusion:** A new MA-II system has been developed allowing use of the high resolution MA as an alternative to a standard II and easy switching between the two during a procedure, when the imaging task demands. The MA is shown to provide increased CNR for all vessel phantoms in a uniform head-equivalent scattering material. This combined system should lead to improved neurovascular image-guided interventions. (Partial support from NIH Grants R01EB002873, R01NS43924, Toshiba Medical Systems Corp., and the Frank B. Silvestro Endowment Scholarship)

SU-FF-I-52

Evaluation of the Contrast-Detail Response of Digital Radiographic Systems Using the CDRAD Contrast-Detail Phantom with the CDRAD Analyser Software

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Purpose: The CDRAD phantom is frequently used to subjectively evaluate the contrast-detail response of diagnostic imaging systems. We investigated the use of this phantom in conjunction with the automated CDRAD Analyser program as a quantitative tool for the evaluation of digital radiographic systems. **Method and Materials:** Three DR systems (Trixell Pixium 4600, Canon CXDI-50G, and DirectRay detectors), and one CR system (35-cm x 43-cm FUJI ST-VI plates) were evaluated under two experimental conditions. For the first, the CDRAD phantom was positioned directly on the detector housing, the anti-scatter grid was removed, and the detector was exposed with two different beam qualities. Quality A: 0.5-mm Cu filtration, ~75 kV, 7.1-mm Al HVL, and Quality B: 0.5-mm Cu filtration, ~125 kV, 10.2-mm Al HVL. The detectors were exposed to ~0.4, ~0.8, ~1.5, ~2.5, and ~5.5 mR, for both beam qualities. For the second condition the phantom was sandwiched between two 10-cm slabs of Lucite, and placed on the patient table. The exposure conditions were the defaults for the Abdomen examination for each system, and the "skin" entrance exposures employed were ~180, ~250 and ~350 mR. Results were compared using the CDRAD Analyser contrast-detail figure of merit IQFinv. **Results:** For the Trixell detector the IQFinv increased with exposure from 6.31 to 7.67 for beam quality A, from 5.45 to 7.43 for beam quality B, and from 2.91 to 3.91 for the Abdomen exam. Corresponding values for the Canon detector were 2.88 to 4.77, 2.50 to 4.61, and 1.56 to 2.14. Those for the DirectRay detector were 2.49 to 5.00, 1.86 to 4.93, and 1.34 to 2.15, and those for the CR system were 2.89 to 4.16, 2.82 to 4.00, and 1.89 to 2.32. **Conclusion:** Our results indicate the potential of the CDRAD phantom/CDRAD Analyser as a quantitative image quality analysis tool.

SU-FF-I-53

Mega-Voltage CT Image: An Attempt to Enhance Image Quality

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Purpose: TomoTherapy uses Megavoltage CT (MVCT) to verify patient position and alignment prior to treatment and it is usually good enough to verify the patient's position and anatomy prior to treatment. However, a greater resolution and contrast in patient images obtained by the MVCT scan would be beneficial in verifying patient anatomy and set-up. The effects that changing the MVCT dose and consequently the signal to noise ratio (SNR) had on MVCT image quality and resolution were studied. **Method and Materials:** A "cheese" phantom with a resolution plug (different size holes) was scanned. The machine pulse amplitude control (PAC) value was varied in intervals from 2.22 to 3.34 to adjust delivered dose and the resulting images were analyzed. The dose was measured with an A1SL ion chamber at the clinically used PAC value of 2.78 to be 2 cGy, 0.4 cGy at a Pac value of 2.22 and 3.8 cGy at a PAC value of 3.34. **Results:** Increasing the PAC value leads to an increase in both dose and energy. In observing the images that were taken, it can be see that the resolution and quality of the image improves as the PAC value is increased. When comparing the MVCT image taken at the normal PAC value of 2.78 and an increased PAC value of 3.34, the smaller diameter density plug holes can be seen more clearly, the contrast between the holes and the cheese phantom are more sharply defined, and the holes appear more concentric for the image taken at PAC 3.34. **Conclusion:** Slightly higher dose during an MVCT scan can improve the image quality and resolution for the TomoTherapy system. These observations will be used in future investigation of more complex imaging tasks to improve MVCT imaging. **Conflict of Interest:** Main author is an employee of TomoTherapy, Inc.

SU-FF-I-54

A Monte Carlo Model of the Discovery ST PET Scanner

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Purpose: To evaluate the accuracy of a GATE (Geant4 Application for Tomographic Emission) Monte Carlo model of a commercial PET scanner for purposes of simulating the generation, propagation, and detection of annihilation photons in PET scanners, and for evaluating image scatter fractions, resolution, sensitivity, and other scanning parameters. **Methods:** We compare GATE results to experimental data from a GE Discovery ST PET scanner. Our 3D PET simulation model of the GE Discovery ST scanner consists of 10,080 detectors grouped in modules and blocks following the vendor's specifications. NEMA'01 PET commissioning phantoms are also accurately modeled. More than 2 billion positron histories were followed to simulate measured PET scans of the NEMA phantom. **Results:** The simulated GE Discovery ST's radial sensitivity ratios for the NEMA'01 phantoms agree to within 0.6% of measured values ($R_0/R_{10,\ measured}$ [9.118/9.309] = 0.979 versus $R_0/R_{10,\ simulated}$ = [9.145/9.289] = 0.985, sensitivities R are in cps/kBq). The scatter fraction agreement is within 1.6% (the measured and simulated scatter fractions are 45.1% and 45.8% respectively). The model also accurately simulates the behavior of the time curves (measured peak true counts 338 kcps at 32.9 kBq/cc and simulated peak true counts 340 kcps at 32 kBq/cc). In addition, the spatial resolution of the scanner is simulated. **Conclusions:** The validated model accurately predicts scanner response and performance parameters, can be used to evaluate and improve PET resolution, image quality, and quantitative accuracy, and will aid in the determination of optimum scan parameters. In conjunction with CT images, the model can also be used to assess the accuracy of tumor segmentation for radiation therapy treatment planning. This work is sponsored in part by National Cancer Institute Grant PO1-CA059017, by the summer fellowship program of the American Association of Physicists in Medicine, and by an internal seed grant.

SU-FF-I-55

Data Mining and Knowledge Discovery Methodology Development Using Predicting Transmembrane Proteins by Synergy of Computational and Molecule Biophysics Approaches as An Example

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Motivation: We consider developing data mining and knowledge discovery methodology in medical physics is important. We use predicting membrane proteins as an example, because such proteins account for roughly one third of proteins encoded in Human Genome and comparative genomes, and play crucial roles ranging from signal transduction to energy metabolism, but their structures can not be determined well by experimental methods. Since Human Genome had been completely sequenced, function and structure of proteins coded for by Human Genome are not known well. In our attempts to construct methods for automated large-scale structural and functional annotation of genes and proteins in Human Genome and comparative genomes, the identification of transmembrane proteins is thus an important, but also very difficult task. We used a broad array of techniques that combined computational and biomedical physics approaches for the above task. **Results:** We developed a hybrid unsupervised-supervised classifier using new variants of the Self-Organizing Feature Map algorithms, in combination with novel Feature Generation, Feature Selection and Ensemble Methods such as Boosting with bagging and boosting with confidence Information. Our combined computational and biomedical physics approaches proved beneficial by showing larger areas in our predictor's ROC curves. We will discuss the effectiveness our synergic approaches, and also provide comparisons to more traditional classifiers such as neural networks, decision trees and support vector machines. The framework that we developed can be broadly applied to other medical physics problems and marks a beginning of methodology development, not only in molecular biophysics and genomics, but also in medical physics.

SU-FF-I-56

Image Quality Testing Using An Oil-Filled ACR MRI Phantom at 3 T

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Purpose: Image uniformity testing at high field clinical MRI scanners is challenging using a phantom filled with aqueous solution due to the dielectric resonance effect. This study aimed to investigate the feasibility of using silicone oil-filled ACR MRI phantom for quality control testing at 3 T. **Method and Materials:** Experiments were conducted on a 3.0 T GE Signa HD MRI scanner using the standard quadrature head coil. Two ACR MRI phantoms, one filled with standard aqueous materials and the other with silicone oil were used for image quality testing following the ACR guidance. Five series of images were acquired, including a sagittal image and four series of axial images, i.e. ACR T1, ACR T2, site T1 (SE, TR/TE=500 ms/ Min Full), and site T2 (FSE, TR/TE=4000/102 ms, ETL=17). Finally, the images were analyzed according to the ACR MRI Quality Control Manual (2001) and the results obtained from the two phantoms were compared. **Results:** The percent intensity uniformity (PIU) obtained from the oil phantom was at least 6% higher than that from the original phantom (88% vs. 82% for ACR T1 and 94% vs. 81% for ACR T2). No significant differences were found in all other measures as obtained from the two phantoms. **Conclusion:** Image inhomogeneity in high field MRI is directly affected by both the coil configuration and the electric properties of the object. Our results indicate that silicone oil is more suitable for use in the routine quality assurance test at high field by minimize the effect from the phantom materials. Filling the ACR MRI phantom with silicone oil permits the same testing procedures without compromising the action criteria for the image uniformity.

SU-FF-I-57

MR Image Quality Testing of K-Space- and Image-Based Parallel Imaging Techniques Using the ACR Phantom

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Purpose: Using ACR MRI phantom testing to evaluate the change of image quality caused by k-space- and image-based parallel imaging techniques in a 3-Tesla MRI scanner. **Method and Materials:** All phantom images are acquired from a 3 Tesla Siemens Tim-Trio MRI scanner. Four sequences, namely ACR T1, ACR T2, Site T1 IR-TSE, TR/TE/TI=2200 ms/11 ms/900 ms, ETL=5 and Site T2 TSE, TR/TE=4280 ms/88 ms, ETL=15 , are scanned with each of the

conventional, GRAPPA (iPAT=2) and modified SENSE (mSENSE, iPAT=2) modes. Images are analyzed according to standard ACR MRI QC procedures on a PC-based workstation. **Results:** The results derived from the phantom images indicating that both of the tested parallel imaging techniques make no significant changes in the degree of the geometric distortion, the high contrast spatial resolution, the measured slice thickness and position accuracy, and the percent image uniformity. The signal-to-noise ratios (SNRs) obtained from all scans are lower while using parallel imaging techniques (SNR_conventional / SNR_GRAPPA = 1.18 +/- 0.08, SNR_conventional / SNR_mSENSE = 1.11 +/- 0.19). The averaged scores of low contrast object detecting test in conventional, GRAPPA, and mSENSE group are 39.3 +/- 0.5, 35.0 +/- 4.4, and 34.3 +/- 3.9, respectively. The percent signal ghosting (PSG) of GRAPPA and mSENSE images are 1.57 +/- 0.72 and 2.26 +/- 1.47 times of that measured in the conventional images. In addition, there is an obvious aliasing artifact observed in the mSENSE groups that cannot be demonstrated by the above data analysis. **Conclusion:** The ACR QC test is able to detect the lower SNR, lower contrast detectability, and higher PSG caused by both k-space- and image-based parallel imaging techniques. More accurate measurement of SNR reduction and improved artifact detection require repeated phantom imaging and additional image analysis.

SU-FF-I-58

Demonstration of the Use of A Capillary Phantom to Monitor DTI Image Processing: Dyadic Sorting of Tensor Eigenvalues

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Purpose: To verify the existence of noise-dependent systematic bias in diffusion tensor imaging (DTI) data using a phantom composed of arrays of glass capillary fibers; and to use the phantom to monitor the corrective effect of using dyadic sorting for alleviating this bias when calculating average quantities in a region of interest (ROI). **Method and Materials:** A phantom containing glass capillary arrays and undoped water was constructed. Seventeen DTI series of images from a 3.0T GE scanner were acquired, where TR was adjusted between series to vary the signal intensity via T1 contrast. Five different values of TR were chosen. Averaging of some of these series together allowed for observations at eight unique values of SNR. Eigenvalues and eigenvectors of the diffusion tensor were calculated as well as fractional anisotropy. After calculation of the average eigenvalues and eigenvectors in ROIs containing the arrays and free water, these average values were used to sort eigenvector-eigenvalue dyadic pairs to maximize overlap between the average values and individual voxel values. Final averages were calculated after sorting. **Results:** Noise-dependent bias was observed using arrays of fibers, resulting in a separation of the two lowest eigenvalues which should be equivalent. Dyadic sorting assists with correcting this bias, although usefulness is confined to regions of lower FA and with higher SNR. Iterative sorting does not greatly improve the performance. **Conclusion:** This work suggests that glass capillary arrays can be used for monitoring systematic bias at a variety of SNR values, and for quantifying the amount of correction that one will observe using a particular scheme, in principle. Future investigation will examine the efficacy of other correction schemes.

SU-FF-I-59

Relative SNR Benefits of Dynamic Arterial Spin Labeling at 3T as Determined by Simulation and Comparison with Imaging at 1.5T

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Purpose: To demonstrate the benefits of brain perfusion imaging at high magnetic field MR scanner using Dynamic Flow-sensitive alternating Inversion Recovery (FAIR) spin labeling technique as compared to standard FAIR at lower field. **Method and Materials:** FAIR signal behavior as a function of the inflow time (TI) at 1.5T and 3T were simulated for both dynamic and standard FAIR methods. Simulations were performed considering initial inversion of the magnetization, it's subsequent T1 recovery, in-flow of blood into the slice and signal reduction due to repetitive RF excitations (Look-Locker sampling) in dynamic FAIR. Experimental brain perfusion imaging of healthy volunteers (n=3) was performed on GE scanners. **Results:** The results showed overall signal behavior in dynamic FAIR is almost independent of readout rate. This means the temporal resolution of imaging can be increased to any desired amount as far as the scanner hardware permits. On the other hand multiple small readout flip angles will induce smaller perturbations than larger flip angles however for a given magnetic field dynamic FAIR with small flip angles lead to lower SNR as compared to standard FAIR. But given the same noise level a low flip angle dynamic FAIR would lead to higher SNR as compared to standard FAIR at 1.5T. For flip angle=20 the relative SNR of dynamic FAIR at 3T to standard FAIR at 1.5 for TI=500, 1200 would be 1.42 and 1.60 respectively. **Conclusions:** Significant increase in temporal resolution and SNR in FAIR arterial spin labeling technique can be achieved by performing multiple (dynamic) readouts after FAIR preparation. By implementing dynamic FAIR at higher field strength the quality of FAIR images in terms of SNR would be even much higher than standard FAIR imaging at lower field strength. This improvement can be further enhanced by repeating the dynamic FAIR more and averaging the results.

SU-FF-I-60

3D Wavelet Packet Denoising of Arterial Spin Labeled MR Perfusion Images

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Purpose: To develop a 3D denoising approach based on wavelet packet decomposition for denoising MRI brain perfusion weighted images acquired with Flow-sensitive Alternating Inversion Recovery (FAIR) arterial spin labeling technique. **Method and Materials:** A 3D multi-resolution wavelet packet decomposition approach was developed that takes advantage of both spatial and temporal correlation between multiple consecutive slice selective and non-selective inversion recovery images acquired with FAIR technique. Single shot spin-echo EPI-FAIR imaging was performed on 5 healthy volunteers on a 1.5T GE scanner using FAIR inversion time of 1200ms. Other imaging parameters were 64x64 matrix, TE/TR=20/2000ms, and 20 image pairs. To find the best wavelet base, different bases with different levels of decomposition were tested. Then using the best filter and 2D wavelet transform each image was first decomposed and then for each image a threshold was estimated for noise coefficients and wavelet coefficients below that threshold were removed and the image was reconstructed from the remaining coefficients (Spatial denoising). Then these images were fed into the second step of processing in which each pixel's time course along all of the selective and nonselective images was considered as an one-dimensional signal and decomposed again using wavelet packets and denoised based on a separate threshold estimated for each signal (Temporal denoising). Then each image was reconstructed again. **Results:** Among different wavelet packets that were tested Coiflet wavelet packet with 5 vanishing moments, 4 level of decomposition with Shannon entropy and soft SURE threshold (for smoothness and preservation of the edges) criteria resulted the best performance in terms of PSNR and minimal distortion after reconstruction. The mean PSNR of the denoised images was 22.29 ± 4.2. **Conclusion:** Denoising based on our proposed method in general significantly improves the acquired FAIR perfusion-weighted images. This improvement is associated with blurring of the edges in the image.

SU-FF-I-61

A New Gel Phantom for MRI

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Purpose: To develop a gel-based quality control phantom for MRI that does not suffer from flow artifacts seen in liquid-based phantoms. **Method and Materials:** We have developed a gel based phantom incorporating NiCl and NaCl that does not suffer from flow artifacts. The phantom was evaluated for accuracy of the stated T1 and T2 values, uniformity and dehydration properties. The T1 relaxation time was measured using a spin echo sequence with TR = 1000 mS and TE varied between 10 mS and 350 mS. The T2 relaxation time was measured through a fast spin echo inversion recovery sequence with TR = 1000 mS, TE = 50 mS and TI varied between 50 and 983 mS. All measurements and images were made on a GE Signa 1.5T MRI scanner. **Results:** Measured T1 and T2 values were within 1.3% of the nominal values of 260.3 mS for T1 and 234.1 mS for T2. Uniformity was measured using the ACR T1 sequence of TR = 500

mS, TE = 20 mS. The gel phantom demonstrated a uniformity of 86.5% over its volume in a dedicated head coil, compared to 87.2% for a still liquid phantom in an identical container. The measured mass of 4691 grams did not change over a 6 month period. **Conclusion:** This new gel phantom shows promise as a replacement for liquid MRI phantoms. Future efforts will focus on adapting the gel to other container geometries and modifying the formulation for more tissue equivalent relaxation times and to match the ACR MRI accreditation program phantom. **Conflict of Interest:**
Research sponsored by Computerized Imaging Reference Systems, Inc.

SU-FF-I-62

Hemodynamic Response Without Large Vein Signals: BOLD Imaging Using Diffusion-Weighted Spin-Echo EPI
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Purpose: This study aimed to evaluate the temporal characteristic and variability of hemodynamic responses measured by the diffusion-weighted spin-echo (DWSE) BOLD-fMRI and compare with spin-echo (SE) and gradient-echo (GE) results. **Method and Materials:** Six volunteers participated in this study and using 1.5T scanner. The paradigm consisted of 40 repeated trials for DWSE and 30 for GE and SE, with each trial consisting of 1-s visual stimulation followed by 13-s fixation. The GE images were acquired by a single-shot GE EPI, with TR/TE/FA =1000ms/60ms/75°. SE EPI were used to measure DWSE and SE BOLD signals with TR/TE=1000ms/80ms.Bipolar diffusion gradients were incorporated into SE EPI with b values of 50($DWSE_{50}$) and 200 s/mm^2($DWSE_{200}$). Activated voxels were detected by correlating with a gamma variate function. The time series of selected ROI within the visual cortex were extracted for each pixel and averaged randomly across repeated single trials. **Results:** Statistically earlier onset times and remarkably smaller variance at the same CNR level (controlled by averaging different number of trials) were observed with the DWSE than the GE data, with SE performed in between. No significant difference was found between $DWSE_{50}$ and $DWSE_{200}$. **Conclusions:** Since DWSE technique is able to null the intravascular signal and more sensitive extravascular signal around small vessels, we suggest DWSE could more accurately detect onset time. Further, the curve profiles in GE and SE showed a good correlation with exponential decay and in $DWSE_{50}$ and $DWSE_{200}$ correlated well with linear decay. In other words, at higher CNR the onset time variance may approach constant for GE and SE but continue decreasing for DWSE. The curves of $DWSE_{50}$ and $DWSE_{200}$ overlapped, which suggests b value of 50 s/mm^2 may be sufficient to eliminate the large vessels' contamination on the determination of the onset of BOLD fMRI responses.

SU-FF-I-63

Evaluation of the Turn Variation of Spiral RF Surface Coils for MR Microscopic Imaging and Spectroscopy
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Purpose: The purpose of this study was to enhance the technical improvement which can develop the advanced sensitive RF surface coil to investigate the sensitivities of the multi-spiral surface coils and eventually achieve the high resolution of microscopic MR images and MR spectra. **Method and Materials:** The simulation of a coil's magnetic field was processed in MATLAB. Biot-Savart law provides information about the relation between the amplitude and the position. The experiment was processed in the Oxford magnet (1.5T), Copley gradient (25mT/m) coil and Analogic RF amplitude system. The diameter of a coil was fixed at 4cm, and the turn of a coil was increased with a spiral turning method. **Results:** 1. Simulation of magnetic field. The magnetic field strength was increased close to the wire because of a ring-shape wire coil. This simulation was performed assuming no obstruction in the current and domain. Thus, the shape and the field distribution of a RF surface coil were able to be visually analyzed. 2. Coils' performance. The ROI with approximately 3cm was identified by a water phantom in 1.5T. The three and five turned spiral coils were developed and their Q-factor and bandwidth were estimated. **Conclusion:** The present study showed that the sensitivity of RF surface coil was improved by the increasing the number of a spiral coil's turn, and also the SNR of RF surface coil was dependent upon the number of a spiral coil's turn. However, the sensitivity was not proportional to the number of a spiral RF coil's turn. There is an optimal vale in a spiral RF coil turn and sensitivity. In order to obtain a high sensitivity as varying the spiral RF coil's performance, it is important to find the optimal number of turn. This study provides an efficient approach to designing high-field RF coils.

SU-FF-I-64

Modification of Multidirectional Distortion for DTI and Tractography
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Purpose: To modify the assigned optimization of acquisition parameters for precise measurement of diffusion in anisotropic systems. **Materials and Methods:** Diffusion weighted MR data were acquired from healthy volunteer, using 1.5T Siemens Avanto (Siemens, Erlangen, Germany) with actively shielded magnetic field gradients (maximum amplitude, 40mT/m). The parameters for optimal schemes were derived for each measurement based on the estimated mean diffusivity and T2 measurements. Data were analyzed on an independent workstation (Pentium IV, 3.2 GHz CPU). The diffusion weighted images were corrected for gradient tables and ECC using DTI Studio software (Radiology, Johns Hopkins University, SOM). **Results and Conclusion:** Each individual measurement of Dxx, Dyy, and Dzz can be optimized in the way as with optimal diffusion weighting the x, y, z, and other index. The more precise assessment of Tr(D) is needed, the more measurements should be made. In our study, consider the variances of each of the unique elements of the diffusion tensor. **Acknowledgment:** This study was supported by a grant of the Seoul R&BD Program, the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea. (02-PJ3-PG6-EV07-0002) and a grant of the 2005 Nuclear R&D Plan Program, Ministry of Science & Technology, Korea. **References:** 1. Jones D.K., Horsfield M.A., Simmons A. Magn Reson Med 1999;42:515-525 2. Westin C.F., Maier S.E., Mamata H. et al Med. Ima. Anal. 2002;6:93-108 3. Melhem E.R., Mori S., Mukundan G. et al AJR 2002;178:3-16

SU-FF-I-65

Assessment of Advanced Algorithm in Non-Linear Curve Fitting for DSC in Human Brain
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Purpose: To develop an advanced non-linear curve fitting (NLCF) algorithm for dynamic susceptibility contrast (DSC) study of the brain. Methods and Materials: Twenty healthy volunteers participated for the acquisition of T1-weighted and T2*- weighted dynamic contrast enhanced (DCE) MR imaging. Sequential images were continuously recorded during the first passage of contrast agent with the signal intensity for ROI. The generalized kinetic model with NLF was modified with the consideration of coefficient factor. **Results:** The blood perfusion and volume estimation were accurately evaluated in the T2*-weighted dynamic contrast enhanced (DCE)-MR images. From each of the recalculated parameters, a perfusion weighted image was outlined by using the modified non-linear curve fitting algorithm. The present study demonstrated an improvement of an estimation of the kinetic parameters from the dynamic contrast-enhanced (DCE) T2*-weighted magnetic resonance imaging data with using contrast agents. Conclusion: In conclusion, we developed non-linear curve fitting algorithm for DSC study. And the data point from the gamma-variation curve fitting with Levenberg-Marquardt could be useful to achieve the physiological information in the clinical cases. **Acknowledgement:** This study was supported by a grant of the Seoul R&BD Program, the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea. (02-PJ3-PG6-EV07-0002) and a grant of the 2005 Nuclear R&D Plan Program, Ministry of Science & Technology, Korea. **References:** 1. Tofts PS, Brix G., Buckley DL, et al. JMRI 1999;10:223-232 2. Li K-L, Jackson A. Magn Reson Med 2003;50:1286-1295 3. Calamante F., Pell GS. Thomas DL. J Cereb Blood Flow Metab 1999;19:701-735

SU-FF-I-66

MRI Relaxometry BMD Measurements Using Conventional Phase Symmetrized Rapid Increased Flip Spin Echo and Standard Gradient Echo and Its Correlation with DXA

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Purpose: Recently, several special MRI protocols have been developed for BMD measurements for deriving R2(=1/T2), R2*(=1/T2*) and R2'(=R2*-R2) applied in several cross sectional studies. But, due to high slew rate gradients with high amplitudes in small periods, such protocols can be used only in system with high slew rate (22 mT/m.s or greater). However, our main aim in this study was to develop optimized versions of standard GE and conventional SE protocols using in existing MRI systems for BMD measurements, as most systems do not support such newly high slew rate protocols. **Method and Materials:** This study was performed by 1.5T-MRI system(Picker Vista-Q800, slew rate=13mT/m.s), SNR phantom (1.25g/l $CuSO_4$, T2=200ms) for calibration, a body RF-Coil, cross sectional study with 12 normal, 12 osteopenia, 12 osteoporosis volunteers done with a Lunar DXA system-(DPX-MD). To determine R2* and R2, simple standard-GE and conventional phase-symmetrized-rapid-increased-flip-SE(PRISE) protocols with different TE/TR were applied. Then in coronal section of femoral-neck, relaxation rates were compared with BMD from DXA. The optimized conditions of the protocols for R2* measurement standard-GE protocol with TE=13.42/18/26.8ms, TR=800ms and ST=8mm(CV(R2*)=2.96%) and for R2 measurement PRISE protocol with TE=36/54/63/72ms, TR=800ms and ST=8mm(CV(R2)=3%), receiver bandwidth of 21.2 kHz for PRISE, 31.75kHz for GE, Matrix=190x256, FOV=45cm leading to good SNR. **Results:** The overall Pearson's correlation coefficient of R2*, R2' and R2 vs. BMD were calculated as 0.62($p<0.003$), 0.62($p<0.003$) and 0.03($p<0.9$), respectively. Based on the R2* and R2' parameters, significant difference between normal and abnormal groups (osteopenia and osteoporosis) were found. However, there was no significant difference between osteopenia and osteoporosis groups using the relaxation parameters. **Conclusion:** R2* and R2' showed a significant positive correlation with BMD. Therefore, in accordance with DXA values, the results showed standard-GE and conventional-SE(PRISE) could be proper protocols for BMD-measurements in femoral-neck even in low slew rates systems.

SU-FF-I-67

Magnetization Transfer After Bee Venom Acupuncture Treatment to Osteoarthritis

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Purpose: Magnetization Transfer (MT) is based on well-defined biophysical and biochemical properties. Bee Venom Acupuncture(BVA) demonstrated anti-inflammatory and analgesic actions oriental clinical trials. The purpose of the present study was to evaluate the data from experimental and clinical studies and to show further ways to better comprehend the effectiveness of BVA and MT. **Materials and Methods:** In order to achieve our objective it was necessary to optimize a suitable interleaved Magnetization transfer contrast (MTC)/ GRE . Using a 1.5T GE system, set in Ja-Sang Korean Oriental Hospital, was imaged with MTC parameters suggested by Barker GJ et al . **Results:** MTC assessed compositional and structural changes and thickness measurements to assess loss of cartilage substance. In principal, all these techniques are applicable in vivo. Compositional and structural properties are considered to reflect earlier stages of disease and may thus improve the chances to depict potentially reversible alterations. **Discussions:** Cartilage volumetric properties and cartilage loss may be involved later in the course of the disease but are easier to be described. MRI quantification of cartilage volume is based on the acquisition of a high resolution 2D data providing good contrast between the cartilage and the surrounding tissues in the joint as well as a homogeneity of the signal within the cartilage in order to facilitate semi automated segmentation. **Conclusions:** Articular Cartilage(AC) is a tissue capable of transferring and distributing impressive forces across a joint. Venom injected by BVA have created hope that cartilage breakdown can be modulated. These ways creates a need for a non invasive diagnostic tool that can provide quantitative parameters and contribute to evaluate the efficacy of these therapeutic efforts..

SU-FF-I-68

False Positive Analysis of Functional MRI During Simulated Deep Brain Stimulation

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Purpose: Recent studies showed that MRI can be safely performed on patients with deep brain stimulation (DBS) device in place when the stimulator is turned off. By interleaving the DBS and echo-planar imaging (EPI) acquisition, functional MRI (fMRI) may be a useful tool for understanding the mechanism of DBS as well as helping the localization of electrodes. This study aimed to investigate the possible false positive activations due to the limited time interval between the end of DBS and the start of EPI acquisition. **Method and Materials:** The study was performed using a 1.5-T Philips MRI scanner with a DBS electrode (Medtronic, Minneapolis MN) positioned in the center of a gel-filled phantom. The experimental run consisted of alternative 5 stimulation-off and 4 stimulation-on blocks (the stimulator was turned on for 2 seconds immediately after each readout). The control run consisted of total stimulation-off blocks. A single-shot GE EPI (TR/TE = 6000ms/60ms, FOV = 192mm, matrix = 64x64, SW = 3mm) was used, with 10/30 slices per measurement in for long/short inter-scan waiting times (ISWT). Data were analyzed using SPM2. False activation and deactivation volumes were computed at different statistical thresholds. **Results:** For both activation and deactivation, no false positive voxels were detected for all conditions at corrected $p<0.05$ or uncorrected $p<0.001$. For uncorrected $p>0.001$, number of false activated/deactivated voxels increased with p-value increased. No increased trend was observed with the experimental conditions as compared to the control conditions. Similar trends were observed when comparing activation vs. deactivation and long vs. short ISWT. **Conclusion:** An ISWT of 2230 ms (TR= 6s, 30-slice acquisition) was found to be sufficient for placing a 2-s DBS without increased false positive detections of activation/deactivation. A statistical threshold of $p<0.001$ or tighter is recommended for fMRI involving the similar amount of total voxels as this study.

SU-FF-I-69

The Impact of Sparse Data Sets On the Quality of MR Images

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Purpose: To evaluate the impact of reduction in acquired data size on the final appearance of MR images and to assess the synergetic impact of image interpolation, used in softcopy viewing, on the perception of image quality. **Method and Materials:** A rapid progress in signal quality of the MRI data acquired with modern MRI hardware, coupled with a desire to speed up the acquisition times as much as possible, promotes a practice where drastic reductions in the size of acquired data are implemented by the MRI system operator. Routinely, the physician viewing the MR images is presented with incomplete and confusing information about the true size of the acquired data. Most physicians are oblivious to the potential impact of complex acquisition algorithms on the quality of images. The situation is further confounded by various image interpolation techniques used by softcopy display systems.

A standard spin echo imaging sequence (270/10, FOV 30 cm, slice thickness 5 mm, gap 5 mm, 11 slices, 1 NEX, BW=2*15.63 kHz) was used to generate a baseline image with 256*256 acquisition matrix. This was followed by an acquisition of a 512*512 image that served as a "golden reference standard", given the fact that the standard MR displays use 512*512 image size as a default. The baseline protocol was then repeated by varying options and parameters that affected the sizes of the acquisition matrix, processing matrix, or display matrix. **Results:** Images other than the golden reference standard exhibit artifacts whose strength strongly depends on the resampling algorithm applied. The extent and severity of observed artifacts increases with the number of options used to generate the image. **Conclusion:** The image acquisition parameters and display resampling algorithms need to be carefully accounted for when evaluating image artifacts in MR images.

SU-FF-I-70

Asymmetric Spin Echo in FMRI at 3T: A Quantitative Evaluation of BOLD Response and Signal Drop Off

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Purpose: To quantitatively evaluate the fMRI BOLD response of the asymmetric spin echo (ASE) EPI acqusition and signal drop offs at 3T. Applications in the frontal cortical and orbital frontal cortical (OFC) areas from finger tapping and olfactory stimulation were investigated. **Method and Materials:** ASE EPI was developed and tested on a 3.0T scanner. Phantom was used for quantitative distortion measurement by the GRE-, SE-, and ASE-EPI sequences. For olfactory testing, subjects were presented with 12s of olfactory stimuli interspersed by 28s of air with a total scan time of 7 minutes. Subjects were trained to inhale and exhale following a prompts on the screen. Eight subjects were studied for finger tapping and six subjects for olfactory. The BOLD intensity and correlation were measured in the frontal cortical area for finger tapping, and in the orbital frontal area for olfactory stimulation studies. **Results:** The signal drop off is relatively small when the echo shift is 5 msec and 10 msec compare to SE-EPI, but is significantly better compared to GRE-EPI. The optimal BOLD response from olfactory test was detected by ASE with 35 msec TE, and 10 msec echo shift. Almost no BOLD effect detected from SE at TE of 35 ms and with ASE at TE of 35 ms and 5 ms echo shift. Echo shift of 15 msec had strong artifacts. GRE-EPI was not useable for the olfactory study because almost all the signal dropped off in the OFC area. **Conclusions:** ASE-EPI offers reasonable BOLD response without significant reduction in the slice coverage like SE-EPI. It can detect BOLD response where the signal is small and susceptibility is strong. GRE-EPI is preferred when the BOLD response is located in the less susceptible areas. ASE-EPI with 10 msec echo shift appears to be optimal for olfactory study at 3T.

SU-FF-I-71

Diffusion Tensor Imaging Analysis Using Mapping Analysis in Temporal Lobe Epilepsy

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Purpose: Diffusion tensor imaging (DTI) can provide information regarding early pathological changes, such as neuronal cellular changes in gray matter or demyelination in white matter tracts. Voxel-based statistical analysis can be performed to compare changes in a group of patients and control. In this study we investigated whether the seizure focus in patients with temporal lobe epilepsy (TLE) can be identified compared to controls. **Method and Materials:** Ten normal control (36±7y) with no history of neurological disease, and 10 TLE patients (30±10y) diagnosed with temporal lobe epilepsy were included in this study. The ADC and FA maps acquired from each patient was compared to the normal group data, and also the whole patient group was compared to the control group on a voxel-by-voxel basis using SPM. **Results:** In this study we investigated whether the patients with temporal lobe epilepsy showed abnormality in DTI compared to normal controls. The three of ten patients, a well localized region in the temporal lobe gray matter was found to show significantly increased ADC, which might be associated with the seizure focus As the long-term seizure may damage the tissues, the involved areas may show changes in DTI. Every patient showed a different pattern, some with a well-localized focus with increased ADC which might be associated with seizure focus. The FA maps were also analyzed, however no significant changes were found localized in the white matter, rather in the same gray matter area, suggesting that the effect was mediated from ADC changes. **Conclusions:** The SPM analysis of ADC maps acquired from each individual patient compared to a normal group might provide a means of accurately identifying focal abnormalities prior to more invasive diagnostic procedures and possible epilepsy surgery. The occult epileptogenic regions may be identified using voxel-based statistical analysis of ADC.

SU-FF-I-72

Evaluation of Dual-Energy Subtraction of Digital Mammography Images Under Conditions Found in a Commercial Unit

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Purpose: Radiological contrast-to-noise ratio (CNR) has been calculated for subtracted images of calcifications after dual-kVp subtraction combining beams available in a Senographe 2000D. **Method:** 2002 Lemacks' et al. formalism has been used in the CNR calculations. Assumed spectra were from 1997 Boone et al. parameterization and the study was limited to a lowest 25 kV Mo/Mo and a highest 40 kV Rh/Rh beams, and 1R total exposure. **Results:** For a standard case combining 25 kVp Mo/Mo and 40 kVp Rh/Rh beams (total mean glandular dose about 2.5 cGy) predicted maximum CNR for 300 m calcification in 5 cm thick, 50% glandular, breast is about 1.2, below Rose's criterium for visualization for standard case. The effect that input factors might have on predictions has been evaluated. Choice between alternative spectra can affect CNR by 50%, assumed calcification composition leads to differences of 67% in calculated CNR, and assumed breast tissue composition can alter CNR by 45%; these results are weakly dependent on calcification or breast thickness, or on the assumed fraction of glandular tissue. CNR values are related to detected spectra effective energy. Calculations predict that above 37 kVp Mo/Mo beams are more energetic than Rh/Rh at same kVp, due to beam hardening. **Conclusions:** This work has found differences of the order of 40-70% in calculated CNR depending on the choice of any of the following model parameters: initial spectra, calcification composition, and breast tissue composition. The evaluation gives modest results for the CNR (values smaller than the Rose's criterium) in the subtracted microcalcification images using the equipment beams, but improvements could be attained by hardening the high-energy exposure beam.

SU-FF-I-73

Comparison of the Effects of Viewing Conditions and Viewing Angle On Object Dectectability for Different AMLCD Displays

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Purpose: The ability to interpret images displayed on active matrix liquid crystal displays (AMLCD) can be influenced by factors such as display luminance, surrounding background, room illuminance and viewing angle. We have been investigating how these parameters influence reader scores with images featuring both small objects and low contrast as typically seen in mammography. We are in a position to make some comparisons between the results obtained with displays from two different manufacturers. **Method and Materials:** Reader studies were conducted using a computer generated contrast detail phantom alternately presented against a display background of selected luminance levels. Luminance was also measured at different viewing angles and at four selected room illuminance levels. Image scoring was performed at each combination of background level, viewing angle and room illuminance level. **Results:** Image scoring performance was interpreted using k values, which reflect the contrast and diameter of the objects detected in the images. The best image scoring results were obtained when viewing angles were kept small, and also when room illuminance was at the level of 5 – 10 lux. Better scoring results were also obtained when the image background luminance was adjusted to 5 – 20 % of maximum. These results differ from what had previously been found when evaluating displays from a different manufacturer. In this case the best scoring results were obtained at zero background and the room illuminance did not seem to have a significant effect on the results obtained when kept in the range of 0 – 20 lux. **Conclusion:** The results support the view that while it is advisable to keep the viewing angle to a minimum, it may be advisable also to adjust the room illuminance and monitor background luminance to specific levels which may be best suited for a particular AMLCD display.

SU-FF-I-74

Comparison of Image Quality in Contact and Magnification Modes in Digital Mammography

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Purpose: To compare image quality in contact and magnification modes in digital mammography. **Method and Materials:** Images of three anthropomorphic breast phantoms were acquired using a Hologic FFDM system. First, images were acquired in contact mode with grid. The exposure parameters were determined by AEC. Second, images were acquired in 1.5x magnification mode without grid. The exposure parameters were selected such that the detector entrance exposures were the same as those in the first experiment. The third, images were acquired in contact mode with grid and with the same patient doses in magnification mode. Image quality was analyzed using MIPAV software. **Results:** 9lp/mm and 6lp/mm were resolved in the magnification mode and in the contact mode respectively. However, the smallest specks group in the phantoms (0.13 mm) could be detected in all modes. For masses and fibers, more features were detected in the magnification mode when the detector entrance exposures were fixed at those determined in the contact mode. More masses and fibers were detected in contact mode when the breast skin entrance exposures were the same as those in the magnification mode. **Conclusion:** At the same patient dose, the contact mode provides better detectability of masses and fibers. The detectability of microcalcification above 0.13 mm is not improved by using the magnification mode. The detectability of smaller microcalcifications (<0.13 mm) needs further investigation.

SU-FF-I-75

Geometric Magnification in Digital Mammography

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Purpose: The goal of this study was to investigate the effect of varying geometric magnifications on the edge definition as well as conspicuity of calcifications in images obtained using a full field digital mammography system. **Method and Materials:** Images of the wax insert of an ACR mammography phantom, sandwiched between two clear acrylic slabs simulating scattering in breast tissue were obtained on flat panel FFDM system at five different geometric magnifications between 1.4 and 2.2 plus a contact image. The x-ray technique was the same for all images. All images were viewed on a soft copy work station. Observers were asked to judge the quality of the images in terms of edge definition (largest speck group) and conspicuity (two smallest speck groups) and assign a score on a scale of 1 to 4 for each speck in the group. Additionally, the system MTF was measured using the edge method at each of the magnifications in order to correlate the system response with the observer scores. The MTF was measured in the anode-cathode (AC) direction as well as perpendicular (LR) to it. **Results:** The trends in the scores indicated that the conspicuity of the smallest speck group increased with magnification. The edge definition of the largest speck group was found to increase and then decrease depending on the magnification, reaching a maximum at a magnification of 1.6. This correlates well with the measured MTF in the LR direction. **Conclusion:** Geometric magnification improves image quality in digital mammography. Conspicuity of the smallest calcifications improves with magnification. However, this is accompanied by a decrease in the edge definition of the larger calcifications after a magnification of 1.6. The optimum magnification depends on the specific task (edge definition or conspicuity).

SU-FF-I-76

Observed Inter-Camera Variability of Clinically Relevant Performance Characteristics for SIEMENS Symbia® Gamma Cameras

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Purpose: To evaluate the inter-camera variability of clinically relevant performance characteristics for Symbia® gamma cameras (Siemens Medical Solutions, USA). **Materials and Methods:** Evaluation of the inter-camera variability was based on measurements made with nine separate systems. Performance characteristics measurements were based on NEMA standards and AAPM Reports (#22 and #52). All of the measurements were performed using Tc-99m (except Co-57 for extrinsic resolution) and low-energy high-resolution collimation. Of the nine cameras, 4 have 3/8" and 5 have 5/8" crystals. Energy resolution, intrinsic and extrinsic spatial resolution, intrinsic integral and differential flood uniformity over the useful field-of-view, pixel size, deadtime, sensitivity, SPECT resolution, and SPECT integral uniformity were evaluated. The mean, standard deviation, and coefficient of variability (CV) of each metric were computed for each crystal thickness. **Results:** The mean (standard deviation) of the measured metrics for the 3/8" and 5/8" crystal systems, respectively, were as follows: energy resolution [FWHM-%] of 9.5 (0.2) and 9.5 (0.3); intrinsic resolution [FWHM-mm] of 3.46 (0.08) mm and 3.87 (0.09) mm; extrinsic resolution [FWHM-mm] of 4.39 (0.09) mm and 4.70 (0.10) mm; integral uniformity [%] of 4.5 (0.4) and 4.7 (0.7); differential uniformity [%] of 2.6 (0.3) and 2.7 (0.2); pixel size [mm] of 0.601 (0.001) and 0.602 (0.001); maximum count rate [kcps] with 20% deadtime loss of 125 (18) and 130 (13); sensitivity [cpm/ Ci] of 203 (5) and 217 (8); SPECT resolution [FWHM-mm] of 13.2 (0.1) and 13.4 (0.1); and SPECT integral uniformity [%] of 0.14 (0.02) and 0.13 (0.01). The mean and maximum CV were determined to be ~6% and ~17%, respectively, with the intrinsic uniformity, deadtime, and SPECT uniformity displaying the greatest CV amongst the different systems. **Conclusions:** All of the tested gamma cameras exhibited performance characteristics within specifications and the inter-camera variability was observed to be low.

SU-FF-I-77

Photon and Electron Specific Absorbed Fractions From the UF Pediatric Tomographic Phantoms

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Purpose: To calculate photon and electron specific absorbed fractions (SAF) by utilizing series of realistic tomographic phantoms of pediatric patients. **Method and Material:** The series of UF tomographic phantoms, 9-month male, 4-year female, 8-year female, 11-year male, and 14-year male, developed at University of Florida, were imported into the EGSnrc Monte Carlo code for this study. Monoenergetic photons and electrons were simulated as homogeneously distributed in various source organs. All possible source-target organ pairs were considered to calculate absorbed fractions at the target organs from both internal electron and photon emitters localized in source organs. **Results:** The new sets of photon and electron SAFs were tabulated for the particle energies from 0.01 MeV to 4 MeV. The photon SAFs were compared with those from the ORNL phantoms. It was shown that ORNL phantoms failed to correctly represent the proximities of certain organ pairs and caused significant discrepancies from the UF phantom in terms of photon SAF values. The electron self-absorbed fractions calculated from the UF phantoms were compared to that given in the ICRP Publication 30 assumptions. For higher electron energies, the assumption of 100% self-absorption in the ICRP schema was shown to be incorrect, especially for the smaller phantoms and smaller organs with large surface-to-volume ratios. For example, the thyroid self absorption was only 21% for 4 MeV electrons in the UF 9-month phantom. **Conclusion:** Photon and electron SAFs were calculated for various ages of pediatric patients by utilizing realistic tomographic computational phantoms. It was shown that the tomographic phantoms accurately represent the shapes of various internal organs and their proximities to surrounding organs. The explicit consideration of electron transport demonstrates that the traditional assumption of full energy deposition by energetic beta-particles can be in error, especially for the younger and smaller patients of this age series.

SU-FF-I-78

Estimate Standard Uptake Value (SUV) in F18 FDG PET Tumor Imaging

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Objective: This study was to evaluate factors that may affect SUV in F^{18} FDG PET tumor imaging. **Method:** Twenty patients with single pulmonary nodules and five with multiple nodules were evaluated. Whole body scan was performed one hour post injection of 15 mCi of F^{18} FDG on a dedicated PET scanner (Siemens-CTI Exact). OS-EM reconstruction was employed. Reconstructed images were then transferred to a Siemens eSoft workstation for image display and analysis. Volume of lesion was adjusted around the hot nodule in the pulmonary area. The ROI was automatically defined by iso-contour (10%, 25%, 35%, and 50% respectively) and used to calculate activity in Bq/ml, lesion volume and average SUV within the region. 3-D image fusion started with manual registration based on axial,

sagittal and coronal display of the PET and the CT data. The SUVs were calculated using RoI defined by 50% or 25% iso-contour. The same RoIs were applied to dedicated PET data and to transformed image from PET-CT fusion. **Result:** Average lesion size was 3.9 cm^3 at 50% iso-contour and increased to 5.9 cm^3 when the iso-contour was 10%. PET SUV measured 4.77 compared with 4.47 from PET CT fusion image with 50% isocontour and 3.36 compared with 3.79 respectively with 25% isocontour for a large lesion in right lung. Lesion volume decreased about 30%. **Conclusion:** Manually adjusting the iso-contour to fit the lesion based on visual inspection on PET images demonstrated significant difference between a pre-set threshold and image guided iso-contour on the lesion size, activity uptake and the average SUV. Measured SUV and lesion volume (50% isocontour) decreased when the PET CT fusion image was used in comparison with dedicated PET scan.

SU-FF-I-79

Java-Based Plugin for Tomographic Reconstruction for SPECT Data

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Purpose: To implement a plugin for the software ImageJ, a public domain and open source software, written in JAVA, used for image processing and analysis, able to perform the filtered backprojection (FBP) algorithm for tomographic reconstruction of SPECT data. **Method and Materials:** New classes were added to the software ImageJ in order to implement the plugin. The following classes have been developed: (1) the backprojection process, in which data from projections or filtered projection are smeared back into the image matrix; (2) the tomographic reconstruction ramp filter with other windowing possibilities using loss-pass filters such as Butterworth, Shepp-Logan and Hamming; (3) the one-dimensional Fourier transform to perform the projection filtering; (4) and the user interface of the plugin. The plugin was tested with Monte Carlo simulated projection data of Zubal brain phantom, NCAT phantom and patient data. **Results:** The plugin is able to reconstruct sinograms of 8, 16 and 32-bits. Users can choose filter/window combinations. After the user sets the parameters needed for each combination (cutoff frequency and/or order), the filter curve can be visualized. When no filtering is choosen, simple backprojection is performed. The final reconstructed image is displayed and can be visualized or analyzed using segmentation and processing tools available in ImageJ. **Conclusion:** The outcome of this work consists of a plugin for the software ImageJ to reconstruct images from SPECT data as sinograms using filtered backprojection or simple backprojection. The plugin is plataform independent and runs either in Windows or Linux, freely downloadable and accessible, and based on open source code. Further implementations will allow this plugin to work with DICOM images and offer iterative methods of tomographic reconstruction.

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SU-FF-I-80

Monte Carlo Simulations of GSF Family Voxel Phantoms for Quantification of Renal Planar Scintigraphy

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Purpose: To analyze quantitatively the influence of different renal uptakes of ^{99m}Tc-DMSA on the absolute index of renal function (IRF), using Monte Carlo simulated images of voxel phantoms family. **Method and Materials:** Four anthropomorphic phantoms of GSF family (Baby, Helga, Donna and Children) were simulated with SimSET code. The phantoms have different dimensions in the region of interest (e.g. renal depth, distance between kidneys, renal volume, body volume). Planar acquisitions were modeled using a parallel LEHR collimator. The phantoms were positioned 10 cm from the collimator. A 20% energy window was used to acquire ^{99m}Tc projection onto 128 X 128 matrices. The energy resolution was modeled with a 10% Gaussian function. For each phantom, five normal and abnormal uptakes were assigned, from 50%-50% (normal) to 10%-90% (severe). The IRF was calculated using the software DMSAQuant, based on the Raynaud method. The results were compared with true activity in each kidney, known by Monte Carlo simulations. **Results:** The results of the IRF have shown differences between the calculated indexes and the true index. The higher deviations (75%) are associated with lower relative uptakes (10%). For relative uptakes higher than 40%, the difference between the calculated indexes and the true index remains constant between 5% and 10%. **Conclusion:** Our results showed that Raynaud method do not provide accurate values of the absolute IRF when lower relative uptakes are present due to renal diseases. The results have shown that the values of the absolute index of the diseased kidney are influenced by the contralateral kidney. This could be justified because the method only corrects renal depth and age. We suggest that more studies will need to be done to clarify the factors influencing the renal quantification and to model a new correction factor.

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SU-FF-I-81

Gamma Camera Guided Permanent Breast 103Pd Seed Implantation

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Objective: To assess whether a proposed SPECT device could address the requirements of resolving distributions of permanent breast brachytherapy ^{103}Pd seeds following implantation; while maintaining an acceptable imaging time to allow for correction of misplaced seeds. **Method:** Monte Carlo simulations of a cadmium zinc telluride crystal-based gamma camera were used to assess whether the detection of 22 keV photons emitted from the ^{103}Pd seeds was feasible. A hexagonal parallel hole collimator, hole length 38 mm, diameter 1.2 mm with 0.2 mm septa was modeled. The design of the gamma camera device was evaluated on two phantom models. The first model consisted of a simple representation of the clinical problem by simulating the breast as 8 cm diameter sphere of breast tissue containing a central, 1cm cubic distribution of 8 seeds. The second simulation presented a more accurate depiction of the clinical problem, where the breast model was based on the pre-implant CT scan of a typical breast brachytherapy patient and the activity was simulated from the patient's corresponding treatment plan. **Results:** The spherical phantom yielded promising results after 24 s of imaging time, where the maximum error between the center of mass of the seeds in the reconstructed image and the simulated seed location was 1.02 mm. The results from the clinically accurate simulation revealed that individual seeds could not be identified from the reconstructed images after 2 minutes of imaging. However, the strands of seeds, arranged in each needle were localized to a maximum error of 1.9 mm. Conclusion: The online gamma-camera approach to imaging the ^{103}Pd seeds is feasible for simple seed distributions. Additional improvements to the collimator design and the gamma camera orbit are required before the gamma camera device will be able to distinguish each seed in an implanted seed distribution.

SU-FF-I-82

Variability and Accuracy of Standardized Uptake Values in FDG PET Scans

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Purpose: The standard uptake value (SUV) in FDG PET images is used in defining tumor volumes. In lung tumors, an SUV greater than 2.5 may be assumed as tumor. This investigation sought to (1) establish a threshold SUV above which there is significant FDG uptake, and (2) determine other variables leading to inaccuracies in SUV. **Method and Materials:** Phantoms (SUV calibration, SPECT, and anthropomorphic with heart and lung inserts) with known activity 18F-FDG concentrations were placed end-to-end to simulate a patient torso of 70 cm. A PET system with GSO detectors and Cs-137 transmission source was evaluated. The activities used, scan and transmission imaging protocols simulated those used clinically. The SUV phantom served as reference and had a SUV = 1.0. Ten ml phantom aliquots were counted separately to determine true activity concentrations. **Results:** Three times the noise level of the SUV phantom images determined the threshold for significant SUV. Regions in the SUV phantom yielded a SUV of 0.96 +- 7.7%, and a 1.18 SUV threshold. For ½ activity used clinically, the noise was 12%. The average SUV was the highest at the phantom centers with a range of inaccuracy of at most 20%, attributed to errors in the image reconstruction scatter correction algorithm. Additional errors include incorrect activity and scanner calibrations, and patient weight measurements. These errors can be reduced to very low levels with careful protocol control. **Conclusion:** This study yielded a

threshold of significant SUV of 1.2, but depends on starting activity. Inaccuracies in the reconstruction lead to further variability in the SUV and was 20% in this study. If This inaccuracy level implies that a threshold of 3.0 should be used instead of 2.5. Similar measurements should be carried out on other PET scanners to determine the limits of SUV delectability and accuracy.

SU-FF-I-83

Derivation of Diagnostic X-Ray Spectra Using An Interpolation Program with Calculated and Measured Input Parameters

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Purpose: To determine diagnostic x-ray photon spectra using simple transmission measurements. **Method and Materials:** A database of measured and calculated x-ray photon spectra values from the Catalogue of Spectral Data for Diagnostic X-rays, R. Birch, M. Marshall and G.M. Ardran, Diagnostic Topic Group of the Hospital Physicists' Association, England, 1979 was collected and used to form a multidimensional interpolation matrix. These researchers measured x-ray spectra using a Ge(Li) detector for various x-ray systems in the diagnostic energy range and derived a calculation method to calculate x-ray spectra which agreed closely with measured spectra for different conditions. X-ray spectra for tungsten targets and different inherent filtration in Al and Cu were coded in relative number of photons per mm^2 per keV for kVps ranging from 30 to 140 kVp at 10 kVp intervals. Other parameters were given such as mean photon energy in keV, photon flux at 0.75 m in photons-mA^{-1}-s^{-1}-mm^{-2}, output in micro Gy-mA^{-1}-s^{-1} and exposure in mR-mA^{-1}-s^{-1} and 1st, 2nd, and 3rd half-value layer (HVL) in mm Al. Most spectra were derived for constant potential units but some with ripple were also derived. Target angles included 10, 17, 20 and 22 degrees. **Results:** From this input, interpolation curves were derived which enables one to interpolate between the 10 kVp intervals and to derive the inherent filtration for a particular unit in Al equivalent from simple transmission measurements in Al and mR/mAs at a particular distance. The kVp of the unit was also derived from the transmission measurements by comparison with the calculated curves. **Conclusion:** With some additional data, this method could be used to derive the x-ray spectra for any unit in this energy range, 30 to 140 kVp for different parameters.

SU-FF-I-84

Comparison of LINACs Either Equipped with On-Board Imaging/cone-Beam CT Or CT-On-Rails for IGRT

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Introduction: The purpose of this study is to investigate the advantages and limitations of LINAC equipped with either OBI/CBCT or CT-on-rails with a 6D robotic couch-top for IGRT. **Method and Materials:** An optimal IGRT delivery system should be capable of handling the auto setup of the updated isocenter with 6D corrections, the adaptive radiotherapy, and treating multiple lesions simultaneously. The CT image quality should be suitable for designing a treatment plan. The planning CT and the daily CT are acquired in the treatment setup condition, minimizing systematic errors coiled into the image-data. A 60-cm diameter of maximum field-of-view (FOV) is crucial to scan almost all the patients. The scanning-range in superior-inferior direction should cover the maximum treatment-field available on the delivery system. It should have KVp and MV portal-imaging capabilities for setup verification. Monitor the target-isocenter shift due to couch rotation. A thoracic phantom was used to evaluate the IGRT setup accuracy using either OBI/CBCT or LINAC/CT-on-rails. **Results:** the current CT image quality of CBCT is suitable only for image registration. However, the relative large intra- and inter-variation of CT numbers for the same tissue inhibits the use of CBCT for treatment planning and adaptive radiotherapy. The single scanning-range of CBCT is limited to 14 cm. Both scanners need to increase the FOV to 60-cm diameter. The phantom study indicated that both units could setup the daily isocenter correctly based on the image registration. One of the findings suggests that the rotation corrections are essential for the crucial treatment to avoid treating the critical structures. It should be corrected either through a 6D robotic couch-top or software. **Conclusions:** Based on the image registration, LINACs equipped with either OBI/CBCT or CT-on-rails perform the IGRT treatment nicely. **Conflict of interest:** Supported in parts by SRA grants from Varian Medical Systems, Inc.

SU-FF-I-85

Optimization of Image Quality and Minimization of Radiation Dose for Chest Computed Radiography

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Purpose: To investigate the effects of x-ray exposure parameters and added beam filtration on patient dose and image quality for optimization of chest computed radiography (CR). Method and Materials: A chest x-ray phantom (CardinalHealth Model 76-211) was used to simulate a patient of standard size. To achieve a small or a large patient size, one sheet of 25-mm acrylic was removed or added, respectively. Pre- and post-patient x-ray spectra were measured using a CdTe x-ray spectrometer at various exposure conditions and added filters. kVp stations of 80, 100, and 120 were selected. An Al plate of 0, 1.0, 2.0, 3.0 mm or a Cu plate of 0, 0.1, 0.3, 0.5 mm was placed at the tube exit window for each exposure setting. Patient entrance exposure was measured using a Radcal ion chamber under automatic exposure control at each exposure condition. Corresponding CR images were acquired at above conditions using a contrast-detail phantom (CDRAD) placed between acrylic plates of the chest phantom for evaluating image quality. The same protocol for processing of CR image plate was used throughout. Both printed films and digital images were archived. Reading sessions were conducted to interpret the 72 CR images. Results: CDRAD images were ranked based on image quality. Corresponding patient dose and x-ray spectrum were analyzed. Beam effective energy and spectrum information were evaluated. Optimal imaging condition was determined. In general, with increased beam filtration and effective energy, image quality decreased with dose saving as expected. However, at certain conditions of patient size, filtration, and kVp, image quality actually appeared improved with reduced or comparable patient dose. Conclusion: Proper use of pre-patient filtration can improve CR chest image quality while maintaining or reducing patient dose at carefully selected kVp setting for a patient. Optional filters should be made available for digital chest radiography.

SU-FF-I-86

Commissioning and Evaluation of An Amorphous Silicon Flat-Panel Digital Imaging System (XRD 1640, Perkin Elmer) for Its Application in Proton Beam Therapy

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Purpose: Accurate, patient-specific anatomical information is a prerequisite for successful radiation therapy planning and delivery to the tumor, while minimizing dose to surrounding tissues. A new FPDI system (XRD 1640, Perkin Elmer) was installed and commissioned replacing a CCD and mirror-based digital imager (DI, Optivus). The details of the tests performed during the commissioning will be presented. Methods and Materials: Rando phantom is used for testing patient orientation in the imager. A RMI magnification plate and a radio-opaque ruler are used to measure the magnification factor of the imaging system. A black-hole phantom along with a line-pair phantom, aluminum and copper plates are used to measure the image quality. To test the alignment of two sources (x-ray and proton), the x-rays and proton beam double-exposure (one x-ray and one proton) was done on two cross-wires (one in the aperture and one in front of FPDI) at four cardinal angles. To test the drift of the nozzle, the same test (with two double-exposures) was done for nozzle at fully extended and fully retracted positions and at different gantry angles. **Results:** FPDI requires low x-ray energy settings (90 kVp, 20-40 mAs) for collecting images of similar quality when compared to the previous imager (105 kVp, 250 mAs). The acceptance test showed the maximum high-contrast spatial visibility (resolution) of 0.8 line pairs per mm and the maximum low-contrast visibility (resolution) of 0.5 mm diameter circular objects. The images obtained from double-exposure as well as two double-exposures showed the coincidence within 1 mm. The FPDI images obtained from Rando phantom depicted differences to the images of exported DRRs, which enabled the correct adjustment of the phantom alignment and orientation. **Conclusion:** When compared to the previous

imager, FPDI provides a sharper image for locating the landmarks for patient alignment with less exposure to the patient.

SU-FF-I-87

High Frequency Ultrasound To Monitor Murine Orthotopic Bladder Cancer Model : An Alternative To Magnetic Resonance Imaging

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Purpose: The study of human bladder cancer is often performed using subcutaneous xenograft models. But, a more relevant model is the orthotopic approach where tumors are grown in their native host environment. Studying the growth kinetics of these intraabdominal tumors is much more difficult as they are not accessible for caliper measurements. The purpose of this study is to demonstrate the feasibility of high frequency ultrasound (US) imaging as an efficient and time saving alternative to magnetic resonance (MR) in longitudinal monitoring of an orthotopic bladder cancer model. **Method and Materials:** Eleven athymic nude mice underwent orthotopic injection of 10^6 253-J B-V cells into their bladder walls. MR imaging was performed weekly on a 4.7 T small animal MR scanner (Bruker Biospin). Axial T1 weighted spin-echo and T2 weighted fast spin-echo acquisitions (TR: 700ms,TE: 8.5ms,FOV: 4.0cm x 3.0cm,Matrix:256 x 192,duration:45-50 minutes) were performed. 3D US data (step size:0.25mm, range:12mm, duration:5-10 minutes) was collected using a Vevo 660 (Visualsonics) system operating at 40 MHz. Tumor size at necropsy was measured with a caliper, and volume calculated with the formula $\frac{\pi}{6}(a\times b\times c)$, where a, b, c are the tumor dimensions. **Results:** The MR volume measurements were made from the fused T1 and T2 images, as done in previous experiments. Two independent observers made the MR and US measurements. There was very good correlation between the MR and 3D US volume measurements with Pearson's correlation coefficient of 0.987 ($p<0.05$). The correlation between the US volume and the specimen measurements was 0.793 ($p<0.05$). **Conclusion:** High frequency ultrasound can effectively monitor murine intraabdominal tumor growth. It is a cheaper and faster modality than CT and MR. Extensions of this technology in the future could include orthotopic injections under US guidance, Power Doppler and harmonic imaging with microbubbles for evaluation of tumor vascularity

SU-FF-I-88

The Small Animal Radiation Research Platform: Benchtop Cone-Beam CT

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Purpose: We are constructing a benchtop small-animal radiation research platform to deliver focused, conformal radiation for translational research. An x-ray tube is employed for both irradiation and cone-beam CT imaging. This paper reports on the design and initial results of an integrated cone-beam CT sub-system to provide image guidance prior to radiation treatment delivery. **Materials and Methods:** The design of the platform necessitates cone-beam acquisition with a unique geometry in which projection images are acquired as the animal is rotated about an anterior-to-posterior axis. In these prototype experiments, images of a euthanized mouse were acquired (1 image per degree for 360°) using a phosphor-mirror-coupled CCD camera and with the x-ray tube operating at 80 kVp. We perform cone-beam CT reconstruction via the filtered back-projection algorithm of Feldkamp et al. **Results:** This system produces high-quality CT reconstructions with isotropic resolution and minimal artifacts. Soft-tissue contrast is easily visualized. Reconstruction time is approximately 3 minutes. The acquisition requires approximately 22 cGy dose to isocenter. Work is ongoing to reduce the dose with the use of a higher DQE flat-panel imager, to optimize imaging parameters using the constant voltage x-ray beam, and to automate acquisition and reconstruction. **Conclusions:** High quality CT reconstructions are possible with our prototype small animal system. In conjunction with robotic motion stages, the novel acquisition geometry enables the construction of a benchtop system in which the x-ray tube is used for both on-line CT acquisition and radiation delivery.

SU-FF-I-89

Performance Evaluation of a Unique Transrectal Ultrasound System

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Purpose: To present a performance evaluation for a unique transrectal ultrasound probe for use in prostate seed implants. The ultrasound probe transducer moves inside the probe case while the case remains stationary. This allows imaging in different planes without moving the prostate. Sagittal and transverse plane imaging is available. Electronic longitudinal stepping and sagittal plane rotation of the transducer replaces manual/mechanical movement. **Method and Materials:** The ultrasound probe evaluated was the TargetScan® System from Envisioneering Medical Products (St. Louis, MO). Proper alignment of the needle template and software grid was verified, as well as electronic stepper position accuracy. Image quality was evaluated using a Multipurpose Tissue/Cyst Ultrasound Phantom (Nuclear Associates Model 84-317). Tests included, maximum scanning depth, axial distance calibration accuracy, spatial resolution, high scatter resolution, low scatter resolution, superficial low scatter resolution, and dead zone region limit. All tests were performed with the probe immersed in a water medium. Both axial and sagittal scanning modes were tested. **Results:** Needle template/software grid coincidence (axial mode) was within 2mm, with most measurements being less than 1 mm. Longitudinal stepper accuracy was within 1mm. The following results apply to both sagittal and transverse scanning modes. Maximum scanning depth was approximately 60 mm in the medium. Axial distance accuracy was within 1 mm. Spatial resolution was 2mm axial, 3mm lateral. The 4 mm high and low scatter targets could be resolved. The 2 mm low scatter superficial targets could be resolved at the 2.2 cm and 4.4 cm depths for both sagittal and transverse modes. The dead zone limit was 2mm for both sagittal and transverse modes. **Conclusion:** The TargetScan® System has high image quality and transducer placement accuracy which makes it suitable for both diagnostic scanning as well as image guided prostate brachytherapy.

SU-FF-I-90

Brain Phantom for Validation of Low Frequency Ultrasound Heating Divices

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Ultrasound thermal therapy of the brain may emerge as an independent modality of treating radioresistant tumours. Prior to clinical use, the heating technologies must be accurately evaluated either in animal models or in brain phantoms. In this paper, a gel phantom based on bovine powder gelatin in ethanediol is proposed. A heuristic method was used to determine an accurate percentage of powder gelatin in ethanediol. In our phantom, at 10.54 % of gelatin in ethanediol the following physical properties were obtained: density of 1040 kg/m^3 $\pm$ 1.0 % at 24 ^{o}C; acoustic speed of 1540 m/s $\pm$ 0.8%; the amplitude attenuation coefficients of (61 ± 2), (113 ± 4) and (175 ± 5) dB/m at 1, 1.6 and 2.25 MHz, respectively. The average thermal conductivity in the gel was (0.532 $\pm$ 0.054) W/m/K at 24^{o}C. The sources of uncertainties in determination of acoustic and thermal properties of the gel are discussed. Both the thermal and acoustic properties of our phantom correspond closely to those reported for brain in the literature. The concentration of the gelatin in the solvent is similar to protein content in the brain, thus suggesting that the protein concentration is of primary importance in tissue phantom preparation.

SU-FF-I-91

Computational Representation of In-Vivo Acquired Stenotic Renal Artery Geometries Using Turbulence Modeling

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Purpose: To report on the in-vivo simulation of arterial blood flow hemodynamics using anatomically realistic CFD models constructed through non-invasive CT imaging, in order to facilitate therapeutic decision-making. The methodology is pivotally applied in a case of severe RAS. **Method and Materials:** The highly accurate SST turbulence model is introduced in the simulation of blood flow in the severely constricted region at the ostium of a human renal artery, obtained from CT scans. This work also proposes a systematic creation and examination of simulated

cases of the particular arterial segment after endovascular stent deployment. **Results:** The significance of specific factors relevant to the arterial geometry and their impact on blood flow across the arterial segment are investigated. The increased resistance to flow due to the presence of the atheromatic plaque is quantified. The presence of a stent at the blood inlet of the artery leads to predictable higher velocity profiles at the outlet. The internal differential pressure profiles, the WSS, and the net forces acting on the plaque at peak pulse in the RAS case are found to be considerably higher than the non-obstructed one. Each of these hemodynamic factors is shown to retain sufficient high contrast between stenosed and unimpeded cases in view of their consideration as potential indicators of clinically significant RAS. **Conclusion:** The proposed methodology provides insight on a RAS development, with estimates of a healthy situation and after a potential stent implementation, using modern CT and CFD methods. It allows interventionalists to quantitatively evaluate the hemodynamic significance of RAS both non-invasively and within reasonable time. It provides diagnostic indicators for the selection of angioplasty and/or stenting, ideally even before the patient becomes symptomatic.

SU-FF-I-92

A Computerized Automated Segmentation Methodology for the Recognition of Vessels From in Vivo Acquired DSA Images

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Purpose: In vivo dynamic visualization, recognition and quantification of microvascular networks represent a methodological requirement of both therapeutic angiogenesis and tumor anti-angiogenesis basic research and clinical studies. The purpose of our study was to develop an automated computerized tool for the segmentation of in vivo acquired DSA images. **Method and Materials:** We applied the scale space structural tensor in order to delineate blood vessels. The concept of structural tensor has been extensively investigated and may allow for analysis of local structures, as well as their strength and orientation in local neighborhood pixels. We optimised the image processing software on the basis of the structural tensor concept, and tested the software on a series of DSA images of collateral vessels in the established in-vivo model of chronic rabbit hindlimb ischemia. Firstly, the image is smoothed by a sigma standard deviation 2D Gaussian. Sigma is a free parameter, which controls the scale of the extracted vessels. Finally, the accuracy of vessel recognition was evaluated by direct comparison with the analysis of an expert vascular radiologist, who was considered a priori as the "gold standard". **Results:** The result was a fully automated tool developed in Matlab that can be used to process images as a batch process without any user intervention. Microvessels' recognition sensitivity depended on the value of the sigma parameter. The segmentation performance of the software was tested in the recognition of collateral vessels in digital DSA images of ischemic rabbit hindlimbs. The proposed software was highly successful in delineating vessels of all sizes with an accuracy score varying between 77.24% and 82.12%. **Conclusion:** The proposed method is automatic, robust and escapes human subjectivity. It is a promising new tool for analyzing macro- and micro-vessels in DSA images acquired for either experimental or clinical use.

SU-FF-I-93

Comparison of Seven Similarity Measures for Intensity-Based 3D/3D Image Registrations On CBCT

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Purpose: The goal of this study is to evaluate seven similarity measure functions for an intensity-based rigid-body 3D/3D image registration. The registration method was specifically designed to localize prostates on cone-beam CT (CBCT) images, acquired for the use of daily patient setup, accomplished by maximizing the similarity from the corresponding simulation CT in an iterative fashion. **Methods and Materials:** Registrations were conducted with seven different similarity measure functions (**NCC**-normalized cross-correlation, **EOD**-entropy of difference, **MI**-mutual information, **CR**-correlation ratio, **GC**-gradient correlation, **GD**-gradient difference, and **PI**-pattern intensity), three different transformations (translation only, translation plus couch rotation, and translation plus three rotations), and two preprocessing methods (window-leveling and histogram equalization). For accuracy and robustness estimation, prostate calcifications were identified on the images from four prostate patients (4 simulation CTs + 27 CBCTs), and the average calcification distances (errors) were measured after registrations. Each registration was marked as "converged" if it had less than 5 mm error, and the average distance was used as an accuracy index. **Results:** In general the histogram equalization and higher degree of transformation freedom improved the accuracy. The only exception was NCC, which performed better without histogram equalization. In the order of better performance, we found the convergence rate and accuracy were (96%, 1.7±1.0mm) for GC, (96%, 1.8±1.0mm) for GD, (96%, 1.8±1.0mm) for PI, (93%, 2.0±1.0mm) for NCC, (81%, 2.9mm) for CR, (78%,2.5mm) for MI, (44%, 2.1mm) for EOD. **Conclusions:** Among the seven similarity measure functions, registrations utilizing GC, GD, and PI showed the least prostate localization error on daily CBCT images. Such 3D-3D image registration will be critical in order to make the future use of CBCT more objective, efficient, and accurate.

SU-FF-I-94

Intensity-Based 3D/3D Image Registration for Prostate Localization On CBCT Images

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Purpose: We have developed an intensity-based 3D/3D image registration program for automatic prostate localization on CBCT images. The main application of this program will be the online and offline analysis of CBCT images for daily image guided radiation therapy. **Methods and materials:** The program provides with two different ways of defining region of interests (ROI); rectangular ROI and irregular ROI. The rectangular ROI is generally defined around the pelvic bone for bone matching, and the irregular ROI is around prostate and seminal vesicle for prostate matching. The ROIs are defined on the simulation CT images, and the volumes within which are registered with daily CBCT images. Registration is accomplished by maximizing the similarity within the ROIs. Uphill simplex method is utilized for the maximization, and it stops when the number of iteration reaches a preset threshold, or when the simplex shrinks to a preset simplex radius. Then, the users verify the registration result in three different overlay views, and the treatment machine correction shifts are calculated from the verified registration. **Results:** As a similarity function, mutual information provided very robust and accurate registrations for the pelvic bone registration. In one of our preliminary studies, the prostate registrations with gradient correlation, gradient difference, and pattern intensity showed 1.7±1.0mm average error, estimated from calcification mismatches. The registrations were also compared with the average manual registrations conducted by four clinicians. The isocenter difference in each dimension was around 1.0±0.7mm. The execution time, except the ROI definition and image loading, was around 7 seconds for each pelvic bone and prostate registration on a 1.8 MHz PC. **Conclusions:** Further thorough experiments are due, but the preliminary results indicated that the newly developed program may be able to provide accurate, robust, and fast online and offline CBCT analysis for image guided radiation therapy.

SU-FF-I-95

The Use of Deformable Registration Model to Improve Visibility of the Lesion in Gated PET Images

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Purpose: Gated PET images from a respiration-correlated 4D PET/CT protocol potentially provide more accurate definition of tumor compared to motion averaged non-gated PET images. However, gated PET images have reduced event statistics in each phase bin, due the shorter acquisition time relative to the clinical study. We have previously demonstrated that a deformable registration algorithm can accurately model changes in lung

lesion position from CT images obtained at different respiration phases. The purpose of this study was to evaluate method of deformable image registration to improve the visibility of lung tumors in gated PET **Methods and Materials:** The data for two patients were acquired on a PET/CT scanner using a respiration-correlated PET/CT protocol, which yielded CT and PET images at different phases of the patient's respiratory cycle. For each patient PET and CT data were sorted in 8 bins. Application of a deformable CT-to-CT registration algorithm produced a set of 7 deformation fields that mapped the CT images at different phase bins onto a reference CT phase (end inspiration). The set of deformation fields was then applied to deform the gated PET images to the reference phase. The deformed PET images were summed with the PET image at the reference phase to produce a single PET image. **Results:** We have examined T/B ratio in the images by drawing ROIs in the lesion and in the vicinity of the lesion. The most noticeable changes in visibility of lesion were observed in the periphery of the tumor. In two patients the T/B ratio in the summed warped image sets improved by 80% and 21% in periphery, 31% and 16% in the center of the tumor relative to single gated image. **Conclusion:** Deformable registration can be used to improve T/B ratio and the visibility of lesions in gated PET data.

SU-FF-I-96

Automatic Registration of EPI and DRR Images for Treatment Planning and Delivery Verification

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Purpose: To automatically register electronic portal images (EPIs) and digitally reconstructed radiographs (DRRs) for the verification of treatment planning and delivery based on Average Intensity Projection (AIP) imaging. **Method and Materials:** AIP 4D CT images are obtained by averaging 4D CT images acquired for lung tumors using multi-slice CT simulation. The AIP images are used to represent tumor motion during treatment planning and delivery in extracranial stereotactic radiotherapy (ESRT). Planning DRR images are created for each treatment field. Cine EPIs are collected for each treatment field. The apertures are segmented from EPIs by thresholding, and then used to register the EPIs and the associated DRRs. The segmented EPIs are enhanced to highlight the tumor area. Then enhanced EPIs and DRRs are fused together in the aperture to produce a fusion movie. Cine EPIs are averaged to produce an average EPI. The tumor movement in each EPI is enhanced by subtracting the average EPI from the original Cine EPI. A sequence of tumor movement images is sorted to form a subtraction movie. **Results:** The registration procedure is performed automatically without user supervision. Fusion movies show the target motion against the static background of DRR, providing a visual perception of the moving anatomy around the target. Subtraction movies show clearly the track of the target motion inside the aperture. Periodic displacement of the tumor reflects respiratory movement. The size, deviation, and deformation of the tumor can be observed. **Conclusions:** This technology will benefit the verification of treatment planning and delivery, the evaluation of the patient set up, and the visual inspection of the tumor movement during ESRT. **Conflict of Interest:** Part of this work was funded by Elekta, Inc., Norcross GA.

SU-FF-I-97

Fuzzy Segmentation of Brain Tissue and Optimum Number of Clusters: Application to Quantitative Assessment of Arterial Spin Labeling Perfusion Maps

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Purpose: To perform brain tissue segmentation using Fuzzy C-means (FCM) clustering and find the optimum number of clusters for application in brain perfusion quantification employing Flow-sensitive Alternating Inversion Recovery (FAIR) arterial spin labeling technique. **Method and Materials:** For this study a single-shot spin-echo EPI-FAIR imaging sequence was employed. Imaging was performed using FAIR inversion times of 300, 450, 600, 800, 1000 and 1200. Other imaging parameters were 64x64 matrix, TE/TR=20/2000, 8-channel phased array head coil, and 40 consecutive selective and non-selective inversion recovery (IR) image pairs of healthy volunteers (n=5) were acquired. A FCM algorithm was developed and implemented for clustering the IR images. Also another algorithm was developed to determine the optimum number of clusters based on validity indices proposed in the literature including Partition Index (PI), Separation Index (SI), Beni's Index (BI) and Dunn's Index (DI). **Results:** Optimum TI value for best segmentation results turned out to be TI=800msec. The optimum number of clusters for quantitative analysis of perfusion maps was found to be 6. The measure for the goodness of the clusters was based on a combination of the meaningfulness of the generated clusters and the value of validity indices mentioned above. With 6 clusters, a cluster of grey matter would appear with more tissue homogeneity and less partial volume effect which would result 20-25% increase in average measured signal in that whole segment which would lead to a higher SNR for more robust quantification of perfusion in that area. Partial volume effect seems to be more problematic at grey matter and CSF border **Conclusion:** FCM is a powerful method for the purpose of brain segmentation since fuzziness could be considered as a measure to account for partial volume effect present in the brain images specially at lower resolutions used for perfusion imaging.

SU-FF-I-98

Segmentation of CT Image Using Fast-Marching and Active-Contour

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Purpose: To reduce the workload of manual contouring by developing a semiautomatic method that can successfully perform segmentation of liver, kidney, bladder, lung, and trachea. **Method and Materials:** A Canny edge detector was used to extract edges. The obtained edge image was used by a gradient vector flow (GVF) snake algorithm to deform an initial surface onto the edge. For the GVF snake to work, the initial surface has to be reasonably close to the edge. This problem was solved by using a fast marching algorithm on the Canny edge image. Several measures were adopted to prevent the initial surface to leak through the places where the edge was broken. **Results:** This segmentation method was tested on clinical CT images and found to be very successful in liver, kidney, bladder, lung, and trachea. There are cases when the organ to be segmented contacted with other organs and there is no image contrast observed between them. Small error may exist in those areas. Those errors can be easily identified and corrected by some simple human interactions. **Conclusions:** Our study has shown that the algorithm we developed can successfully perform CT image segmentation of several important structures. This algorithm can greatly reduce the workload of contouring the patient.

SU-FF-I-99

Implementation and Evaluation of Automatic Contour Propagation in 4DCT of Lung

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Purpose: To implement and evaluate automatic contour propagation in 4DCT of lung **Method and Material:** 4DCT of lung cancer patients was acquired and GTV contoured in each of 10 respiratory phases. Demons-based deformable registration was performed to find the volumetric mapping from the exhale reference phase to each other phase. Contours were propagated using volumetric methods. Usually, the GTV is contoured on one reference phase (end-exhale for example) of the 4D-CT which is copied and edited on the others phases. This is a very important, but time consuming task that is inconvenient for every day clinical use. Using a deformation field computed between 4D-CT phases could accelerate the contouring process. The reference GTV contour would be deformed from one phase to another and the clinician would have to do only small adjustments. The contouring time spent would be significantly reduced. The question is if deformable registration could be used as a semi-automatic contouring tool. We compared differences between GTV reported with and without deformation from one 4D-CT phases to another. Three metrics were used to assess the quality of the contour propagation: the volume intersection and two volume differences. **Results:** Volume intersections between manual and automatic contouring were generally between about 85 and 90 per cent, while volume differences were generally between 5 and 15 per cent. Differences between manual and automatic results were correlated with the variability of manual GTV volumes

delineation between phases. **Conclusions:** Deformable registration is a viable option for contour propagation, and may be used to assist the clinician in defining the GTV for large 4DCT data sets. **Conflict of Interest:** This research was supported by Elekta Oncology Systems and Varian Medical Systems

SU-FF-I-100

Investigate Between the Voxel Based Morphometry and Region of Interest Study in Alzheimer's Disease

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Purpose: Voxel based morphometry (VBM) has been increasingly applied to investigate differences in brain morphology between a group of patients and control subjects. VBM permits comparison of gray matter (GM) volume at voxel-level from the entire brain, thus is an efficient method for assessing regional differences. The purpose of this study was to assess the regional GM volume loss measured by VBM in Alzheimer's disease (AD) compared to controls, and to measure hippocampal volume using manually delineated volumetry and compare the results to VBM findings. **Method and Materials:** Twenty-three AD (mean age 70 ± 8y; m/f= 7/16, Mini-Mental State Exam [MMSE]= 22.2) and 20 cognitively normal elderly control subjects (mean age 69 ± 4y; m/f= 10/10) were included in this study. The 20 sets of images were first normalized and create the probability maps for segmentation. Normalized hippocampal volume to the intracranial volume was compared between AD and control groups. **Results:** The AD group had a lower GM %, and a higher CSF% compared to controls. The total intracranial volumes analyzed using SPM and our own ROITOOL program were very close ($p<0.0001$). The hippocampal volume of AD patients was significantly lower than that of controls ($P<0.001$). The region includes parahippocampal gyrus, cingulate, insula, frontal lobe and middle temporal complex. Despite the high significance in manual ROI analysis, hippocampus was not revealed in the VBM. **Conclusions:** We found that the hippocampal volume in AD was significantly smaller than in controls using ROI-based volumetry. However, although our VBM results demonstrated that AD patients had a significant atrophy in middle temporal lobe, parahippocampus and insula, the hippocampus was not revealed. While VBM can be applied to assess global atrophy efficiently, manual volumetry is needed to study irregularly-shaped subcortical structures.

Exhibit Hall F

General Poster Discussion
Joint Imaging/Therapy

SU-FF-J-01

3-D Computed Rotational Angiography for Radiotherapy Planning for Cerebral Arteriovenous Malformations: Comparison of Tomotherapy and Non-Coplanar Dynamic Arcs

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Purpose: Three-dimensional Computed Rotational Angiography (CRA) provides high quality images of the complex anatomical structure of cerebral arteriovenous malformations (AVMs). The objective of this research is to combine CRA, as an alternative to bi-plane angiography for target definition, with innovative radiotherapy techniques for stereotactic radiation therapy. This preliminary treatment planning study investigates the utility of Helical Tomotherapy, as compared to multiple non-coplanar dynamic arcs using a conventional linear accelerator (linac). **Materials and Methods:** A Siemens Axiom scanner was used to acquire CRA images for this treatment planning study. Non-coplanar dynamic arc treatments were planned using Theraplan Plus. These plans were designed for delivery on a conventional linac (Varian 2100 EX) equipped with a multileaf collimator (5 mm leaf width at isocentre). The same images and regions of interest were used to generate plans for helical tomotherapy delivery (TomoTherapy Inc., Hi-Art II). Tomotherapy is a dedicated intensity modulated radiation therapy system that delivers a narrow fan-beam, modulated by binary multileaf collimators (6.25 mm leaf width at isocentre). **Results:** The CRA images have an isotropic voxel spacing of less than 0.38 mm, with a signal-difference-to-noise-ratio greater than 20:1. These high quality images facilitated the delineation of the complex target volume for treatment planning. Each of the treatment planning techniques offered specific advantages. Multiple non-coplanar arc plans generated a lower integral dose to the surrounding healthy tissue (a 12 Gy isodose volume of 40 vs. 100 cm^3 for presented sample patient). Tomotherapy inverse-planning provided a more homogeneous dose distribution over the target volume (homogeneity index of 1.006 vs. 1.087), as well as better avoidance of critical structures (maximum brain stem dose of 8.2 vs. 13.2 Gy). **Conclusion:** Tomotherapy presents an alternative to forward planning with non-coplanar arcs. Moreover, the megavoltage CT imaging capabilities of Tomotherapy could provide frameless, stereotactic localization for AVM radiotherapy.

SU-FF-J-02

3D Target Localization Using Cone-Beam CT for Head and Neck IMRT Patients

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Purpose: To evaluate clinical effectiveness of target localization using cone-beam CT (CBCT) for H&N IMRT treatment. **Method and Materials:** All H&N patients treated with an IRB approved protocol were imaged on the first day of treatment and weekly thereafter with Varian On-Board Imager. After the patient was aligned with skin markers, 2D kilovoltage portal images were acquired and compared to the planning DRRs for set-up corrections (2D-based correction). Then, CBCT images were acquired and registered with the planning CT by matching both soft tissue and bony landmarks, which generated the 3D-based corrections. The difference between two correction measurements yielded the treatment isocenter variation using the 3D/3D matching method. Dose distributions with different isocenter deviations were re-constructed on the planning CT. The treatment DVHs of PTVs and critical structures were compared with those in the original plan. **Results:** A total of 12 CBCT were analyzed for 3 patients during their first 4-weeks of treatment. Compared to set-up variations, anatomical shrinkage/deformation was negligible. The mean isocenter deviations after 2D-based corrections were 1.1mm in AP direction (max 3.0mm), 2.6mm in lateral direction (max 5.0mm), and 3.8mm in SI direction (max 6.0mm). For the worst isocenter deviation, the reconstructed mean PTV dose was reduced by 3.6% from the planned mean value. For two patients, the mean brainstem dose increased from 33% to 49.5% and from 36.9% to 66.8%, respectively, in worst cases after 2D-based correction. Other critical structures that received significantly higher doses were cord (max dose changed from 41.8% to 64%), eye (mean dose changed from 37.5% to 83.9%) and parotid (mean dose changed from 58% to 72.5%). **Conclusion:** For H&N IMRT treatment, CBCT image-guidance improves localization accuracy compared to 2D-based technique and should be the method of choice for target localization when tight margins are applied.

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SU-FF-J-03

4DCT-Based Study of Lung Tumor Motion Reproducibility

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Purpose: To investigate the reproducibility of lung tumors motions and their characteristics during the course of the treatment. **Materials and Methods:** Two 4DCT scans were obtained at an interval of about three weeks with a GE-scanner and Varian's RPM System under free breathing for 13 patients. Each respiration cycle had 10 phases. 14 GTVs and 10 lungs in all phases were contoured. Geometrical characteristics of these structures were obtained with Eclipse TPS for the motion reproducibility analysis. **Results:** The GTVs of the initial scans ranged from 2.0cc to 280.5cc with a median of 50.3cc. Their median relative change in the second scan was a 28% decrease. The 3D extent of the respiration-induced motion of the GTVs' centroids in the first scan ranged from 0.34cm to 1.78cm with a median of 0.90cm. For the second scan it was 0.13cm, 1.99cm, and 0.89cm, respectively. The largest motion was in a projection on a sagittal plane. The overall displacements of the GTVs' edges exhibited same trend. These motion tracks from two scans overlapped along DICOM directions. The median change of phase 50 lung volumes in both scans relative to the tidal volume at the first scan was -12% for ipsilateral and -11% for contralateral lungs. The median tidal volume

change between scans relative to the first scan volume was 8% for ipsilateral and 4% for contralateral lungs. **Conclusion:** Most of the patients results show reproducible patterns of motion. The hysteresis of the motion varies between scans. This might be due to GTV changes during the treatment. A large and anisotropic shape change perturbs the initial motion trajectory, however general patterns appear repetitive. The respiratory changes of lung volumes were similar. They are not indicative of the GTVs motion reproducibility.

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SU-FF-J-04

A Computerized Method for Peak and Valley Detection in Respiratory Waveforms Without Flow Measurement

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Purpose: To develop a computerized method for reliable peak (end inspiration) and valley (end expiration) detection in respiratory waveforms for gated radiotherapy and 4D CT. **Method and Materials:** A computerized method for peak (end inspiration) and valley (end expiration) detection in respiratory waveforms without flow measurement is described. The respiratory period *T* was estimated by applying a Fast Fourier Transform. The intercepts of the respiratory waveform with a moving average curve were determined with an averaging width of 2*T*. Peaks and valleys were defined respectively as the maximum and minimum between pairs of interwoven intercepts. While this method worked well the majority of the time, both automatic corrections and manual user interventions were employed to correct errors and adjust the results. **Results:** The method was implemented in MATLAB on a PC with a 3.0 GHz Pentium IV CPU and 2.0 GB RAM. On average, the respiratory waveform was 575.3 s long and contained a total of 307 peaks and valleys. For each patient, 99% of all peaks and valleys were correctly located by the automatic algorithm in 2.8 s. Only three (1%) points required manual user adjustment. A user spent 66.8 s for reviewing, and manually adding or deleting points. For nine of the 20 patients, all peaks and valleys were automatically detected. The high efficiency of the automatic algorithm is clear. **Conclusion:** The results demonstrated that this method was reliable and efficient for peak detection in respirator waveforms with noise and large variations in baseline level, amplitude and period.

SU-FF-J-05

A Deformable Phantom for Dynamic Modeling in Radiation Therapy

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Purpose: The vast array of research projects aimed at measuring and managing intra-fraction motion in treatment planning and delivery demand sufficient quantitative means of verification. While analytic models and patient data are useful, a reproducible, compartmented, mechanical phantom is critical to proper commissioning and use of new systems for physiological motion management. In this study we evaluated the reproducibility of a deformable lung phantom for various simulated breathing states. Methods and Materials: A diagnostic thoracic phantom was modified for this purpose. The abdominal cavity insert was removed, and an extension of the existing lung insert was created using high density foam. To mimic lung density, the foam insert was infused with iodine. Tumor-simulating inserts of varying density and size were inserted and fixed to the foam at different positions. A programmable actuator-driven diaphragm was created to compress/decompress the foam according to an arbitrary breathing profile. Repeat CT scans of the phantom at different diaphragm positions were acquired and the locations of the tumor-simulating inserts were measured. **Results:** The phantom has been demonstrated to produce compression as well as reproducible breathing states. All tumor positions are reproducible to within 1.5mm (with a maximum of 3.5mm deviation for the most inferior large tumor) over multiple repeat scans at the same simulated breathing state. Compressions of over 60% of the foam insert have been demonstrated, with propagation of motion ranging from 95% of the actuator motion at the diaphragm to about 20% near the "apex" (the interface with the existing lung insert). Hounsfield units equivalent to the relative attenuation of lung (~20% of water) were achieved in the uncompressed foam. **Conclusion:** This phantom is simple, efficient, and viable. Experiments in quantitative dynamic modeling of breathing-induced deformations are underway using this system.

SU-FF-J-07

A Low-Z Target with No Flattener and Reduced Energy for Improved Contrast in Megavoltage Cone-Beam CT

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Purpose: To improve contrast in MV cone-beam CT using a low-Z target (LZT). **Method and Materials:** A high-Z tungsten target (HZT) at 6 MV and low-Z carbon targets of different thicknesses were used with no flattener. The maximum energy was used with LZT while eliminating primary electron leakage into the monitor chamber. Output and dose distributions were measured. Images were acquired at 7 frames/sec with a 1024x1024 400-micrometer pixel flat panel detector with 1mm Cu build-up and a Lanex fast scintillator. Phantoms were QC-3V, a contrast/spatial resolution phantom, a sheep head and a cadaver. **Results:** Beam energy was 3.5±0.5 MeV and 4.5±0.5 MV for the 1.016 cm and 1.35 cm carbon targets, respectively. The higher energy was more stable with higher output: 0.299 cGy/sec compared to 0.084 cGy/sec. Surface dose was 80%. Field diameter at isocenter was limited to 36 cm by the electron monitor, when present. Computed contrast-to-noise ratio (CNR) for the contrast-spatial resolution phantom for LZT was 3.5 times that of HZT at 10 cGy. Computed CNR for HZT for the 2D QC-3V phantom images is 24 and for LZT is 100 with dose per projection of 0.035cGy. The f50 of LZT is 0.41 lp/mm. Adaptive noise filtering with a kernel of 8x8 increased the CNR by a factor of 2.4 without degrading resolution. Preliminary cone beam images with the low Z target show remarkable bone contrast and indicate improved soft tissue contrast. **Conclusion:** A stable 4.5 MV beam was produced on a standard treatment linac equipped with a carbon target, showing improved CNR over images taken with the treatment target and sufficient output for cone-beam CT. A direct comparison to images taken with the carbon and tungsten targets on the same cadaver, expected to show an improvement in soft tissue contrast, will be available at the meeting.

SU-FF-J-08

A Novel Method for Image-Guided Verification of SBRT with An EPID in Cine Mode

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Purpose: The adoption of stereotactic radiosurgical techniques for extra-cranial treatment sites is predicated on a high accuracy and precision of tumor localization before *and during* each treatment. We introduce a novel method for monitoring the tumor location while the treatment beam is on by using a conventional electronic portal-imaging device (EPID). **Method and Materials:** In our clinic, we are currently treating some liver patients under a Phase-I IRB-approved extra-cranial radiosurgery protocol. Prior to treatment planning, multiple (n > 2) gold fiducial markers are implanted on the periphery of the tumor. At the time of treatment, the patient is placed in a stereotactic body frame with abdominal compression. After the set-up orthogonal portal images are taken, the EPID is left in its acquisition position. When employed during treatment, the EPID, in *cine* mode, collects the exit radiation and produces a sequence of images for each field. By the end of treatment, a collection of images will be available in PortalVision for review. For advanced analysis and quantification, the images are exported and evaluated off-line. **Results:** Given the length of hypofractionated treatments (due to the high dose delivered), we are able to acquire as many as 78 images for each field. The implanted gold markers are visible in the images even before processing. We use an in-house program for calculating the location of the seeds and their relative distance to the planned location (as defined by the DRRs).**Conclusion:** We have developed an algorithm for quickly assessing target localization using implanted gold markers as surrogates. Not only is this information used to verify the treatment, but it may also be used in the future to adapt the treatment either for subsequent fields or remaining fractions. **Conflict of Interest:** This work was partially supported by a grant from Varian Medical Systems, Inc.

SU-FF-J-09

A Novel Non-Rigid Image Registration Algorithm for Radiation Therapy Using P-Element Based Biomechanical Model (PBM)

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Purpose: Daily pre-treatment volumetric imaging can be acquired with onboard CT or MR simulator. This imaging can be used for adaptive radiotherapy (ART) provided deformations occur on time scales >15-30 min. A necessary component of ART is automatic, fast and robust deformable registration. An algorithm using p-element based biomechanical model (PMB) is presented. Its performance is compared with published algorithms. **Method and Materials:** PBM achieves successful registration using a coarse mesh by "automatic adaptivity", whereby convergence is achieved by iteratively increasing the order of the polynomial used for fitting without necessarily requiring mesh refinement (i.e. distance scaling of mesh element), resulting in linear scaling in computation time. A conventional biomechanical model (BM), which utilizes second order polynomial, requires mesh refinement at each iteration for convergence, resulting in an exponential scaling in computation time. For intra-modal deformations, the performance of PBM was compared with Demons method (DM) for T1-weighted MR and CT using simulated transformations and clinical data. **Results:** DM resulted in certain anatomical structures either missing or misplaced since it assumes that pixel intensity does not change between the target and reference images for the same structure. PBM and BM provided similar results in terms of faithful structural connectivity and accuracy, and were superior to DM. The number of p-elements in PBM was 360, much less than the 1616 elements in BM, allowing for automatic mesh generation to be more robust for PBM. Furthermore, mesh refinement was necessary in BM in order to achieve convergence. The computation time for PBM was 15% less than BM, and 100% more than DM.**Conclusion:** PBM provides a superior accuracy compared to DM. It has accuracy comparable to BM but with reduced computation time.

SU-FF-J-10

A Novel Signal-Processing Strategy for in Vivo Ultrasonic Imaging of Brachytherapy Seeds

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Purpose: Brachytherapy is proving to be a well-accepted means of treating prostate cancer. Unfortunately, implantation using needles inserted transperineally causes gland movement, and the resulting distortion may cause seed misplacement and dosimetry errors. Our approach employs novel methods of digitally processing ultrasound echo signals to markedly improve ultrasonic imaging of seeds during the implantation procedure. This approach will enable the radiation oncologist to determine where all implanted seeds are located and to make additional implantations to correct for dosimetry errors cause by misplaced seeds.
Method and Materials: Our signal-processing strategy uses singular spectrum analysis (SSA) and shows promise for ultrasonically detecting and imaging radioactive seeds implanted in the prostate. This SSA-based strategy utilizes pairs of eigenvalues derived from the autocorrelation matrix of envelope-detected radiofrequency echo signals to identify seed-specific signal repetitions. The power spectrum associated with a repetition signal is computed to derive a P-value indicative of the likelihood of the presence of a seed at the location of that repetitive signal. P-values throughout each scan plane are then color-coded and superimposed on the corresponding conventional grayscale ultrasound images. These new ultrasound images are thus readily usable by clinicians to locate seeds. **Results:** Simulations assessing performance as a function of different levels of white and speckle noise and in the presence of signals at repetition periods not associated with seeds; experiments in an ideal scattering environment; and *in vitro* experiments using seeds implanted in beef were conducted and led to encouraging results. Simulations showed robustness to noise (signal-to-noise ratio < 25 dB) and *in vitro* experiments allowed for seed detection and imaging.**Conclusion:** Overall, our SSA-based strategy shows encouraging potential for seed detection and imaging in the operating room. Clinical implementation of this methodology would be straightforward because it uses enveloped-detected signals directly available from clinical scanners.

SU-FF-J-11

A Novel Use of a Real-Time Tumor Positioning System in Reducing Cone Beam CT Artifacts

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Purpose: The Calypso® Medical 4D Localization system is capable of tracking real-time dynamic motion without ionizing radiation. A limitation of any fiducial based system is the inability to visualize surrounding tissues. Cone beam CT (CBCT) of moving objects results in image blurring due to long acquisition times. We investigated the use of the Calypso® 4D localization system to improve motion artifacts obtained from the Varian Trilogy CBCT. **Materials and Methods:** A research Calypso® 4D tracking system was installed in a Varian Trilogy vault. A rectangular phantom with implanted transponders was attached to an internally-developed 4D stage. A CBCT was obtained while moving the phantom under the Calypso® measurement array using a patient tumor derived trajectory. The projection images were obtained and shifted using the corresponding Calypso® transponder positioning information and then reconstructed into CBCT images. This process was repeated for a dog with transponders implanted in the lung as part of an IRB-approved study. **Results:** The Calypso® based image shifts caused the radiographic projection of the transponders remained stable in sinogram space. CBCT images from the shifted sinogram exhibited reduced image motion artifacts. Without artifact reduction, the transponders were visualized as multiple streaks and the surface of the phantom was heavily deformed. With artifact reduction, the transponders were accurately localized, and the deformation was removed. The dog's breathing cycle made qualitative image motion artifact reduction review difficult. Quantitative analysis of the reconstructed CT numbers showed sharper gradients through the transponders, indicating that the shifting process had improved the image quality. **Conclusions:** Use of a wireless electromagnetic implanted transponder system for motion correction of CBCT is possible. This preliminary sinogram shifting technique was very effective for non-deforming objects. Further work will increase the synergy between real-time tracking systems and volumetric imaging.

This work was supported by Calypso® Medical Technologies.

SU-FF-J-12

A Phantom Study to Compare 2D Electronic Portal Imaging with 3D KV Cone-Beam Imaging

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Purpose: To compare patient positioning using a 2D Electronic Portal Imaging Device (EPID) with a 3D registration technique that uses a kV Cone Beam (CB) device. **Introduction:** The Elekta kV CB device represents a significant advancement in on-line imaging for patient positioning and structure delineation. There exists an obvious interest in studying the robustness of this new technology. The phantom-based study reported here compares the cone-beam imaging capability with conventional EPID 2D imaging and registration. Additionally, a technique was developed to generate digitally reconstructed portal images (DRPIs) from the CBCT and compare them to EPID images. **Materials and Methods:** A Rando anthropomorphic phantom had surgical screws placed in the pelvic region. A treatment isocenter was selected in the pelvic region of the CT dataset of the phantom. The phantom was initially positioned using the CB volume imaging capability. Known shifts of the phantom were introduced and the phantom was repositioned using the CB. The CB corrections were compared to the corrections obtained using the internal fiducials and EPID imaging. Additionally, the EPID-based positioning was mimicked by simulating the 2D imaging using the 3D CB data set. The digitally reconstructed images (DRR) were generated from the CBCT set and used as DRPIs. They were compared to both the diagnostic CT DRR's and the EPID images. **Results: and Conclusion:** The CB and EPID shifts were well correlated as determined by linear regression analysis. The correlation between the DRPIs and the EPIDs was even higher using the same analysis. However, on the shift-by-shift basis the CB was more accurate than the EPID: it gave more accurate shift determination than the EPID for approximately 90% test shifts. The DRPIs had the advantage

over the CB 2Dimages because they included the treatment isocenter, field edges and distance scale.

SU-FF-J-13

A Simple Method to Calibrate Stereo-Vision System In Image-Guided Radiotherapy

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Purpose: To calibrate a 3D stereovision system (or 3D camera in short) with complex planning and treatment systems to implement a 3D image-guided radiotherapy system. **Method and Materials:** A calibration template with a printed grid is used to correlate the treatment machine coordinate system to the 3D camera image coordinate system. The calibration template is carefully placed on the top of the treatment machine table and precisely aligned with the corresponding machine axes. A 3D surface image of the template is captured by a 3D camera mounted on the ceiling of treatment room. Nine points of the 3D surface image are manually digitized and used to calibrate two coordinate systems. Two algorithm, analytical method and multi-points registration method are conducted to find the transformation parameters. The analytical method only needs 3 points to find a rigid transformation between two coordinate systems. Trigged by least-squares approximation, the multi-points method uses 9 points to find an optimum rigid transformation between two coordinate systems. **Results:** Results from a set of experiments demonstrated that both methods can provide acceptable accuracy (<1-mm) for the image-guided radiotherapy. Ideally, all points of the template surface transformed from the calibration should be in the O-XY plane but due to image nose and calibration uncertainty, large error (up to 2 mm) can be introduced by the analytical method. In contrast, for the same template image, the multiple-point registration approach provided image transformation with the maximum error in the template plane less than 1.0 mm under the noisy circumstance. **Conclusions:** Both methods can be used for accurate image system calibration. However, the multiple-point registration method yields more reliable results than that of the analytical method. Both methods are simple and the calibration can be conducted weekly with the QA of radiotherapy systems.

SU-FF-J-14

A Simulation Program for Cyberknife Treatment Setup

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Purpose: During the setup of Cyberknife patients with extracranial tumors, it is always a challenge to tell the angles of misalignment (roll, yaw and pitch) from the two digital reconstructed radiographs (DRRs) and the radiographs from two X-ray cameras. Most of the cases, software handles the problem, but in some cases, software fails, it is because of fiducial migration or not enough fiducials to give 6D information (fiducial), or fiducial motion due to tumor motion (synchrony), or the angles are too large for the software to handle (skeletal structure tracking). When this happens, the operator needs to make the right decision fast, in order to shorten the setup time and to deliver the correct dose to the tumor. We decided to write a program to help people in this situation. This program can generate DRRs before and after each transformation. It will be a great learning tool; new users can practice how to set up a patient from a random starting position; we can't practice the setup on a live patient. Experienced users can use it to study setup, learn how the positions of different structures change relative to different rotations. **Method and Materials:** Java programming was chosen to build the software. The DRRs were reconstructed from a series of CT images according to Cyberknife X-ray sources and screens configuration. **Results:** A graphic user interface (GUI) with two DRRs will be presented to the user, user can choose to translate and rotate the patient, two more DRRs will be generated; and a CT slice will also show up on the GUI. The user can identify the features that have the most change in each transformation. **Conclusions:** This program works as expected. It also demonstrates to the medical physics community that we can easily write programs to manipulate images.

SU-FF-J-15

A Study of Some Immobilization Techniques by Using An On Board Imaging System

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Purpose: To study the effectiveness of a head and neck immobilization system and a prostate immobilization technique by using an on board imaging system. **Method and Materials:** For head and neck, the immobilization system includes standard head rests, MEDTEC base plate and standard thermoplastic masks. For prostate, the MEDTEC HipFix system is used. All patients are in supine position. For head and neck, the daily setup is straight forward. For prostate, our Therapists developed a routine to set up patients. Varian Eclipse treatment computer system is used to generate the setup field DRR from 3 mm CT scan. Varian CL21EX with On Board Imaging (OBI) is used to setup the patient. KV or MV portal images of a lateral and an anterior or posterior setup fields are taken, and then align with corresponding DRR by using bony structures. The OBI software gives the couch shifts in vertical, lateral and longitudinal directions. The 3D (or vector) shifts are calculated from the three orthogonal shifts. **Results:** About 900 prostate setups and 300 head and neck setups have been studied. For 52% of prostate setups and 32% of head and neck setups, the 3D couch shifts are 3 mm or less. For 82% of prostate setups and 60% of head and neck setups, the 3D couch shifts are 5 mm or less. **Conclusion:** This study shows that the prostate immobilization technique gives very good reproducibility, and the head and neck immobilization is not as good. We will try to improve our head and neck immobilization method for IMRT purpose.

SU-FF-J-16

A Tool for Off-Line Review of 3D Target Verification and Localization with Cone-Beam Computed Tomography

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Purpose: To implement a clinical tool for off-line review of Cone-Beam Computed Tomography (CBCT) based 3D target verification and localization. Methods and Materials: An in-house 3D target localization and verification tool is being developed to allow physicians and physicists to review daily treatment target off-line. The system provides quick initial target verification via user selected landmark points. An automatic gray-scale registration technique provides fine-tuning of the 3D target localization. It also allows the preference of soft-tissue weighted vs. bony landmark weighted registration. A rigid body 3D-image registration method, using a combination of correlation coefficient and mutual information measurements, has been developed. The registration algorithm uses a downhill simplex optimization technique to search for the best match of the two image sets. This study evaluates the efficacy and accuracy of the system. First, each CBCT and CT pair is manually registered by a human expert. Then these CBCT are input to the software to be registered with the planning CT. The comparison of the computer calculated 3D correction against the manual alignment evaluates the accuracy of the system. **Results:** 5 CBCT sets of prostate cancer patients are tested. The registration is bone weighted to simulate actual treatment target position. For all cases, the bone structures are well superimposed on the fused images. However, part of the prostate and rectum shown certain degree of mismatch due to different rectal fillings between CBCTs and CTs. Overall registration accuracy is as accurate as 1 mm and 1 degree for bone structures. **Conclusion:** An off-line 3D target localization review tool was implemented. For prostate cases, its accuracy is acceptable for clinical use. Further implementation of the tool to other disease sites and evaluation of soft tissue vs. bone based target localization is underway.

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SU-FF-J-17

Accuracy and Dosimetric Advantage of Target Localization Using Stereoscopic Image-Guided Radiotherapy for Lung Cancer Treatment

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Purpose: We analyzed the accuracy of stereoscopic image-guided radiotherapy (S-IGRT) with the ExacTrac® system (BrainLAB AG,

Heimstetten, Germany), and demonstrated the dosimetric advantage for lung cancer treatment. **Methods:** The accuracy of target localization using the ExacTrac system was analyzed by re-scanning ten patients immobilized in the Vac-loc bag with BB tags put on the isocenter marks determined by the ExacTrac system. The re-scanned CT data from each patient was fused and compared to the isocenter locations on the original CT used for the treatment planning. The Active Breathing Coordinator™ (Elekta, Norcross, GA) was employed to minimize the breathing motion effect on S-IGRT. The dosimetric advantage of S-IGRT was demonstrated by comparing the normal lung volume receiving 15%, 30% and 50% of the prescription dose ($V_{15\%}$, $V_{30\%}$ and $V_{50\%}$) between the plans with smaller margins in the S-IGRT and those with normal margins in the conventional radiotherapy for the ten patients. **Results:** The average isocenter shifts using S-IGRT were within 3.4 ±1.7mm in the lateral, 3.6±1.9mm in the anterior/posterior, and 2.2±3.2mm in the superior/inferior directions. The added margins around the CTV to create the PTV were chosen to be 10mm in the superior/inferior and 5mm in radial direction for the lung cancer treatment planning in S-IGRT. For the ten patients with CTV volume from 8.3cm^3 to 43.4cm^3 and lung volume from 2736cm^3 to 3640cm^3, the averages of $V_{15\%}$, $V_{30\%}$ and $V_{50\%}$ were 17.4%, 9.8%, 5.9% for the S-IGRT plans, and 33.4%, 18.2%, 12.8% for the conventional radiotherapy plans with 2cm margins in the all directions. **Conclusion:** The S-IGRT with the ExacTrac system provided highly accurate tumor localization. The margins from CTV to PTV in S-IGRT treatment planning could be reduced significantly due to the accurate target localization which will reduce the lung volume receiving doses in the medium and low ranges.

SU-FF-J-18

Adaptive IMRT Using Cone-Beam CT: A Case Study On Patients with Bulky Head and Neck Tumors

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Purpose: The objective of this work is to demonstrate the feasibility and efficacy of acquiring on-board Cone-Beam CT (CBCT) volume images for adaptive radiotherapy (ART) and image-guided-radiotherapy (IGRT) for patients with bulky head and neck tumors treated with IMRT. **Method and Materials:** The quality of the CBCT volume images acquired on the treatment table was evaluated by measuring the spatial accuracy, contrast, resolution, and the curve for converting CT number to electron density. A patient planning CT volume images were acquired before treatment and at mid-course. CBCT volume images were acquired weekly during treatment. To cover the IMRT fields, two CBCT acquisitions were combined into one volume image using in-house software. PTV and organ contours were copied from the pretreatment CT volume to the CBCT volume and adjusted as necessary. The IMRT plan was applied to the CBCT volume and dose-volume histograms were calculated for the adjusted PTV and spinal cord. The CBCT images were used for patient treatment verifications and dose calculations for ART. **Results:** Significant changes in the skin contours and PTV contours were seen on patients with bulky HNC after as few as five treatments. The dosimetric consequences were also significant. Adapting the IMRT plan to the changes in patient anatomy by re-optimizing on the CBCT volume was found to be feasible. For patients whose Head and Neck cancer was not bulky, there were no significant changes in setup or anatomy.**Conclusion:** It is feasible to acquire weekly CBCT images on the treatment table for analyzing significant changes in anatomy and determine dosimetric consequences of those changes. The CBCT can be used to obtain the accumulative target dose and to modify treatment plans without performing additional planning CT. The CBCT is shown to be a very effective tool for ART for IMRT treatment.

SU-FF-J-19

Adaptive Radiation Therapy Using Helical Tomotherapy

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Purpose: To describe and illustrate the processes required for adaptive radiotherapy (ART) with a helical tomotherapy system. **Method and Materials:** ART is a radiation treatment process where the subsequent delivery can be modified using a systematic feedback of the geometric and dosimetric information in the previous fractions. The first step in the process is CT guidance to achieve soft tissue localization. Dose recalculation is used to determine the dose delivered on a daily basis. Deformable image registration is required to place the daily image set, and hence regions of interest, in a common coordinate system. The total doses delivered are accumulated, and the treatment is evaluated relative to the original treatment plan. If significant deficiencies are noted in the dose delivery, plan re-optimization can be performed to compensate for these deficiencies and make the treatment delivery more closely match the intent of the original treatment plan. **Results:** Prostate and head and neck cases have been used as clinical examples to test this adaptive strategy. Plan re-optimization can maintain plan quality with no major degradation in most cases if two or three re-optimizations are performed during the course of the treatment. **Conclusions:** ART provides a powerful tool to improve the delivery of radiotherapy, especially in situations where there is significant deformation of anatomy during a course of radiotherapy. In addition, it provides a powerful tool to retrospectively or prospectively examine the doses received by regions of interest, and hence, more accurately define tolerance doses for normal anatomy and curative doses for tumors. **Conflict of Interest:** Several of the authors are employees of TomoTherapy, Inc., and portions of this research have been funded by TomoTherapy, Inc.

SU-FF-J-20

An Evaluation of User Variability for Image-Guided Radiation Therapy (IGRT) Shift Determination

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Purpose: To evaluate the Image-Guided (IGRT) shift variability calculated by different users using the same patient data and same IGRT process. **Method and Materials:** IGRT was performed using the Siemens Primatom. This system consists of a Siemens Primus Linear Accelerator and a Siemens Emotion diagnostic CT on rails. Patients have a daily, pre-treatment CT scan taken that is transferred to the Siemens Coherence Workstation where the daily CT is fused with the original treatment planning CT. The fusion is performed so that the daily internal organ or critical structure position can be determined and the organ/structure can be aligned to give the same position relative to the isocenter that was determined from the treatment plan. A shift in the x, y and z directions are made to facilitate this alignment. Four users retrospectively calculated the shifts required for an IGRT patient using the same CT data set and the same IGRT process. The treatment area for the patient was the prostate gland and a total of 39 daily shifts were performed. **Results:** The maximum variation on any one day was 0.90cm in the right/left direction, 1.10cm in the superior/inferior direction and 0.93cm in the anterior/posterior direction. The averages of the maximum daily variations were 0.39cm, 0.54cm and 0.55cm respectively. **Conclusion:** There are multiple systems that will perform IGRT but the advantage to using CT-on-rails systems is the high soft tissue resolution you get from the diagnostic CT sets. The higher resolution allows the user much more information that can be included in the shift evaluation. Our results show the user variability to be acceptable but when implementing this type of IGRT, user variability must be considered.

SU-FF-J-21

An External-Marker Based Non-Respiratory Body Motion Monitoring System

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The development of new technologies has leaded a trend of tighter target margin and longer treatment procedures in the new era of image-guided radiotherapy. This prompts a concern of potential body motion of a patient during the treatment, especially for stereotactic body radiosurgery. The purpose of this study is to develop a technique to monitor the non-respiratory motion of a patient, separated from the relatively large respiratory motion. BrainLab ExacTrac system is used as the platform for the study. Multiple infrared external markers are placed on a patient's chest and abdominal surfaces. The position of each marker is monitored with two infrared cameras. The motion signal of each marker, which is the mixture of respiratory and non-respiratory motions, is recorded. The markers on the chest surface show much smaller, but correlated respiratory signals than those on the abdominal surface. The non-respiratory component can be derived from the motion signal at the chest surface

subtracting the respiratory component represented by the motion signal at the abdominal surface. A computer program has been written to calculate the two motion components in real-time and was retrospectively tested in patients enrolled in a 4D-gated-CT protocol. Total of 24 patients were tested. The duration of recorded motion signals ranged from 10 to 25 minutes for different patients. The extracted non-respiratory motion signal showed reduced respiratory ripples of less than 0.5 mm for most of the patients, with the maximal ripple of about 1.2 mm. It also showed slow-drifts as well as some sharp spikes or irregular fluctuations. The slow-drifts were <1.5mm for 8 patients, >1.5mm and <2.5mm for 6 patients, >2.5mm and <3.5mm for 5 patients, and >3.5mm for 3 patients with maximal drift of 6.5mm. This result suggests that monitoring non-respiratory motion during treatment might be necessary.

SU-FF-J-22

An Image Based Statistical Shape Model and Its Application in Radiotherapy Margin Design

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Purpose: A novel imaging based model is proposed to describe the stochastic nature of the shape and location of a volume of interest (VOI). Based on the VOIs in sequential patient images, the model can predict the probability that a specific point will belong to the VOI. An application of the model is in customized radiotherapy margin design. **Methods:** N sequential patient images taken on-board or online contain *all* VOI information immediately before or during the treatment sessions. Typically these images are already registered in the radiation device coordinates, a signed distance transform (SDT) will be applied to the VOI boundary in each image to generate a distance map $d(\vec{r})$. The sign of $d(\vec{r})$ indicates whether the point $\vec{r}$ is inside (negative) or outside (positive) the VOI. The VOI shape/location random variation around its mean will propagate through SDT into $d(\vec{r})$. It is reasonable to assume that $d(\vec{r})$ is Gaussian and its measured values are independent from each other. Consequently, $t = \frac{\mu(\vec{r}) - \bar{d}(\vec{r})}{s(\vec{r})}$ obeys Student's t-distribution, with $N-1$ degrees of freedom. Here $\bar{d}(\vec{r})$, $\mu(\vec{r})$, and $s(\vec{r})$ are the sample mean, the expected mean, and sample variance of $d(\vec{r})$. By definition of level-set theory, before any more measurement, a point belongs to the expected VOI if and only if $\mu(\vec{r}) \le 0$. The probability that a point $\vec{x}$ belongs to the VOI can be estimated by $\Pr_{VOI}(\vec{r}) = \Pr(\mu(\vec{r}) \le 0) = \Pr(t \le -d(\vec{r})/s(\vec{r}))$. When the VOI is clinical tumor volume (CTV) we can use $\Pr_{VOI}(\vec{r})$ to design our radiation field margin after a cut-off coverage probability p is specified. All points in space with $\Pr_{VOI}(\vec{r}) \ge p$ are included as part of the expected CTV. Thus we effectively generated a planning tumor volume (PTV).**Conclusion:** The model has been tested on real clinical cases. The results show that it is robust and easy to use. The customized probability/imaging based non-uniform margin obtained through this model should be extremely useful in image guided radiation treatment.

SU-FF-J-23

An Image-Intensity Modification Method to Deal with Non-Correspondence Problem in Deformable Image Registration of the Gaseous Rectum

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Purpose: The goal of this study is to develop an image intensity modification method together with the intensity based deformable registration algorithm for auto-segmentation of the rectum on daily CT images. In CT-guided prostate cancer radiotherapy, the planning CT image may contain an empty rectum while there may exist bowel gases in the rectum on any given treatment day (daily CT). The intensity based image registration algorithms alone were insufficient to produce the correct spatial transformations for all objects, especially for the rectum since there was no one-to-one correspondence in the gaseous region. **Material and Methods:** In this study, we proposed a diffusion-based deformable image registration algorithm combined with an automatic intensity modification method that introduces artificial gas pockets in the planning CT based on prior knowledge of the previously contoured rectum. This will allow for the establishment of correspondence between the two CT images. A multi-grid method was used for solving the nonlinear partial differential equation for the displacement field, and this displacement field was used to map the manual rectum contours from the planning CT to the daily CT. 30 CT images with the largest bowel gas fillings from 15 prostate cancer patients were chosen to test the algorithm. **Results:** The intensity modification technique is demonstrated to be effective in correctly delineating the daily rectum. Compared with the deformable image registration method without rectum image modification, the average volume overlap index was improved from 50.6% to 71.2%. This was visually verified by overlaying the segmented contours onto the daily CT images. **Conclusion:** We developed an effective auto-segmentation technique for rectum using a deformable image registration algorithm combined with an image intensity modification method. The approach is fully automatic and capable of handling the special non-correspondence problem in CT images of prostate cancer patients.

SU-FF-J-24

An Optical Flow Based Motion Tracking Method Using Fluoroscopic Video

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Purpose: To present an optical flow-based method for tracking tumor motion and propose a noninvasive respiratory detection method using fluoroscopic video. **Method and Materials:** Fluoroscopic video of a patient is acquired. Only one frame is selected as the reference frame and objects in this frame are manually segmented. The motion of a segmented object is found by computing the average optical flow of pixels within the object. Optical flow provides a two-dimensional motion vector for the displacement of pixels between two frames. The object is moved between frames by moving all pixels by the average velocity vector. Then the position of the object in the new frame is adjusted by applying a template matching algorithm. The algorithm moves the object over a search range of +/- 2 pixels. The object is placed at the position having the maximum correlation coefficient (CC) between the pixels in the original and new frames. This procedure is repeated to advance the object from frame to frame. **Results:**The outlines of tracked objects are viewed superimposed on the fluoroscopic videos. The outlines follow the general motion of the objects without drifting away for the approximately 30 seconds (300 images) and 8 respiratory cycles of a typical video. Objects that do not significantly deform are well tracked. The boundaries of objects that deform are not well described by the tracked outlines, however, the centroid motion of the objects is. The analysis yields the mean displacement of objects. As the distance an object moves away from the reference position increases, the CC decreases. A plot of the CC vs frame shows a sinusoidal curve with the breathing period as does the displacement plot, but with reversed phase. **Conclusion:** The mean motions of objects in fluoroscopic video are well tracked. The displacement and respiratory signal are also obtained.

SU-FF-J-25

An Optimized Dose-Based Patient Alignment Method for On-Line Adaptive Radiotherapy

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Purpose: To develop an on-line patient alignment procedure that fully utilizes the CT guidance and dose verification feasibility in image guided radiotherapy. The new patient position is selected to optimize the plan that is evaluated using the daily contours created based on deformable image

registration. **Method and Materials:** Before a treatment fraction is delivered, a CT image of the patient in the treatment position is obtained. The couch is adjusted to match the planning CT image via on-line image guidance. Verification dose is calculated using this daily image. A deformable registration between the planning image and the daily image is performed and the ROIs are automatically re-contoured on the daily image. The daily dose is mapped back to the planning frame and then accumulated with the previous fraction dose. The new patient position is chosen via a procedure that optimizes the plan evaluated using the daily ROIs. The whole procedure entails the sequential execution of the following tasks: daily CT, CT-guided patient setup, deformable registration and automatic re-contouring, deformation of dose back to reference CT, dose-based patient position optimization, and plan evaluation using cumulative and daily doses. **Results:** The new couch alignment procedure was validated on clinical prostate cancer data that includes a planning CT image and 17 fraction CT images (256×256×47) with resolution of $0.1875\times0.1875\times0.3cm^3$. The whole procedure was completed in a few minutes. The DVH results indicated improved sparing of the sensitive structures and better target coverage. **Conclusion:** The new dose-based patient alignment procedure is an advancement to the image guidance alignment alone. Notable improvement in delivery dose can be achieved for certain types of treatment sites such as prostate cancer where the inter-faction positions of target relative to sensitive structures are not well correlated with the positions of rigid structures and are difficult to predict.

SU-FF-J-26

Analysis of 10,327 Pre-Treatment Ultrasound Localizations for 387 Prostate Cancer Patients Treated with Conformal 3D External Beam Radiation Therapy

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Introduction: Daily 2D ultrasound-based target localization is routinely used for the patient setup in treatment of localized prostate cancer with external beam radiation therapy. A statistical analysis of a large data set can provide insight into target margin definition. **Methods and Materials:** Data from 387 patients treated between 2001 and the end of 2005 was retrospectively analyzed. Every patient in the study received daily pre-treatment localization resulting in a total of 10,327 localizations, each comprising an isocenter shift in 3 directions: anterior-posterior (AP), right-left (RL), and superior-inferior (SI). The mean shift for each direction for each patient was computed from daily treatment records, and a mean of the means was used in the analysis. The standard deviations (SD) for each direction were also computed for each patient and averaged. The data was statistically verified for normality. The mean shifts represent systematic uncertainties in the patient setup, and the SD represent the random variations. **Results and discussion:** The mean distances required for shifting the target to the required position were 6.1 mm posterior (4.4 mm SD), 2.1 mm superior (4.5 mm SD), and 0.5 mm right (3.6 mm SD). The 6.1 mm shift posterior is indicative of a non-negligible systematic uncertainty. There are several sources of this uncertainty, the major one being the difference in patient setup and procedures between the CT simulation and the treatment room. **Conclusion:** Our study has revealed systematic inter-treatment uncertainties. The results support the use of up to a 15 mm PTV margin to encompass the CTV for 95% of our sample, if the ultrasound localization system were not used.

SU-FF-J-27

Analytical Quality Assurance Criteria For CT-MRI Mutual Information Image Fusion

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Purpose: To use point-based error metrics as an analytical criterion for CT-MRI mutual information (MI) image fusion. **Method and Materials:** A commercially available MI algorithm was used to fuse CT and MRI image sets for 5 patients. Three corresponding anatomical landmarks were manually identified on CT and MRI to initialize the fusion algorithm. All landmarks, designated A(CT) and A(MRI), were identified by a single expert user. A program was developed to extract the CT and MRI point coordinates, scaling factors and homogenous transformation matrix M from the commercial system. The parameters were used to calculate the "ideal" MRI coordinates, A'(MRI) = M*A(CT), that analytically always produce zero documented error by the manufacturer's software. The difference between the ideal calculated A'(MRI) and the user indicated MRI data set A(MRI) was then analyzed in terms of standard point-based error metrics, Fiducial Localization Error (FLE) and Fiducial Registration Error (FRE). The program also performs the inverse transformation, A'(CT) = M-1*A(MRI), into CT space for a similar error analysis. **Results:** The FLE was determined, by statistical analysis in the form of the repeated digitization of the anatomical landmarks by the same expert user, to be 0.6mm (+/- 1 pixel). The range of FRE for the 5 patients was 2.2 mm to 2.5 mm. Visual inspection of the MRI points transformed into CT space clearly indicated that the fusion error was as much as 20% of the cone diameter for small treatment cones and therefore clinically significant. **Conclusion:** FREs as large as 2.5 mm are dosimetrically significant given that typical dose gradients in stereotactic radiosurgery are 10%/mm. In addition to being representative of the performance of the MI fusion, FRE should be considered when determining clinical target margins for stereotactic target delineation.

SU-FF-J-29

Assessment of Patient Setup Variations with a Commercial On-Board Imaging System: Is There a Benefit to the Patient?

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Purpose: Kilovoltage imaging with a commercial on-board imager (OBI) has been implemented in our treatment room for image-guided radiation therapy (IGRT). It holds great potential to improve treatment accuracy by reducing the setup errors. However, performing patient setup with OBI costs extra time and effort. Thus, it is important to demonstrate which patient will benefit from this new technique. We have assessed patient setup variations and its dosimetric effect. **Method and Materials:** We perform daily OBI setup on the prostate, head-and-neck (H&N), and central-nerve-system (CNS) IMRT patients. Our setup procedure: (1) Patients were aligned to their skin marks. (2) Orthogonal kV images were acquired with OBI. (3) Setup corrections were made by registering the kV images with DRR's based on bony landmark (H&N and CNS patients) or fiducial markers (prostate patients). Shifts larger than PTV margins were verified with MV portal imaging. Setup data from 2 CNS, 9 H&N, and 10 prostate patients were analyzed. For H&N and CNS patients, dose redistributions that incorporate each day's actual shifts were calculated by rigid-body translation. **Results:** (1) H&N and CNS patients: the random setup variations (standard deviation of the daily data) are 0.15cm, 0.32cm and 0.42cm in LR, AP, and SI direction. The systematic setup variations (the average) are 0.5cm. The largest shift is 1.2cm. (2) Prostate patients: average interfractional variations are 0.26 cm (LR), 0.24 (SI) and 0.39 cm (AP). (3) Dose redistribution in the postplans demonstrated that OBI setup corrections typically don't modify the CTV coverage but frequently affect sparing of the critical organs. **Conclusion:** Our random setup variations were found to be smaller than the PTV margin (5mm). With OBI setup corrections, we can further reduce the PTV margin safely. Our postplans have shown that OBI setup corrections can dramatically improve sparing of the normal structures.

SU-FF-J-30

Automatic Determination of Required Adjustment in Patient Setup for Radiation Therapy

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Purpose: To automatically determine the required adjustment for radiotherapy patient setup from two electronic portal images and rapidly calculated digitally reconstructed radiographs (DRR's) from the CT dataset acquired during CT-simulation. **Method and Materials:** An amorphous silicon EPID (OPTIVUE, Siemens) was used to obtain setup portal images on patients receiving radiotherapy treatment at various anatomical sites. Two orthogonal portal images or a pair of portals with minimum of 12 degree parallax were acquired. A CT dataset obtained during CT-simulation was used in an algorithm that calculated DRR's in approximately 80 ms. An iterative procedure compared the generated DRR with the acquired portal image using as the initial position the treatment plan isocenter and gantry angles. The minimum deviation between the generated DRR's and the acquired portal images was obtained using various similarity measures. The output from the registration algorithm gave the required patient setup adjustment with 6 degrees of freedom (3

couch translation shifts, and 3 rotational shifts) **Results:** The alignment of the acquired portals images with the generated DRR's were evaluated by a radiation oncologist for 37 patients (74 portal images). The agreement between generated DRR's and acquired portal images were within 2 mm in 73 of the 74 images analyzed. The largest deviation was approximately 5mm. The calculated translational shift from planned isocenter was between 1 mm and 7 mm. Rotational shifts were usually less than 2 degrees. **Conclusion:** A robust and intensity-based software was evaluated for automatic patient positioning based on DRRs and portal images. The software shows agreement to within 2 mm as compared to evaluations performed by a human observer for various anatomical sites. The software also provides rotational shifts which are difficult to be determined by a human observer in cases where the magnitude is small.

SU-FF-J-31

Breath-Hold Cone-Beam CT for Patient Setup in Stereotactic Body Radiation Therapy for Lung Tumors

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Purpose: To investigate the feasibility of using breath-hold cone-beam CT (CBCT) on the treatment table to set up patients for stereotactic body radiation therapy (SBRT) for lung tumors. **Method and Materials:** After observing the motion of the patient's lung tumor by fluoroscopy, each patient was taught to hold his or her breath for 35 to 45 seconds. If negligible motion was observed during breath-hold fluoroscopy, a planning CT was obtained during a single breath-hold with a CT-simulator. This breath-hold planning CT was used to design a radiation treatment plan with 7-9 static, noncoplanar beams in accordance with a Radiation Therapy Oncology Group SBRT protocol. A CBCT acquired on the treatment table in three breath-holds was used to set up each patient. A single breath-hold was used for the acquisition of each kilovoltage radiograph and portal image and the delivery of each treatment beam. **Results:** The CBCT setup technique was found to be more reliable than using orthogonal kilovoltage radiographs on the treatment table because the tumor could always be seen in the CBCT images, but not always in the radiographs. For some patients, registering the setup image with the planning CT using only bony anatomy, the only practical method with orthogonal radiographs, would make the setup inaccurate. The time required for CBCT setup was acceptable. **Conclusion:** For setting up SBRT treatments of lung tumors, a breath-hold CBCT on the treatment table is feasible and more reliable than using orthogonal radiographs. For some patients, the CBCT setup is more accurate because the tumor can always be seen in the CBCT images and registering images with bony anatomy alone may not place the isocenter in the center of the tumor.

SU-FF-J-32

Breathing Characteristics of Patients Undergoing Long Treatment Sessions

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Purpose: To quantify the constancy of patient respiratory motion over the long treatment times required for high dose stereotactic body radiation therapy (SBRT) and to assess feasibility of the use of respiratory gating for SBRT **Method and Materials:** The respiratory motion of 26 patients undergoing SBRT to spinal sites was tracked for periods between one and two hours. A stereoscopic infra-red camera tracked reflectors attached to the patient's abdomen, chest and bony areas such as over clavicles, sternum or hips in three dimensions. Variations in the amplitude, period, the mean position of each reflector averaged over several breathing cycles, and phase differences between chest and abdominal reflectors, were examined to monitor for departures from regular diaphragmatic breathing. The fraction of time patients were breathing irregularly between the first and second half of treatment was compared to assess patient tolerance of long treatment times. **Results:** In general, patients showed similar variability in both amplitude and period. Averaged over patients, the percent standard deviations were 30.6% and 29.4% respectively. Changes in relative amplitudes between the abdominal and chest markers, an indicator of a change from diaphragmatic to chest breathing, were infrequent. No increase in the frequency of chest breathing was observed with time. The standard deviation of the amplitudes and periods in the first half of the data was not significantly different from those in the second half, indicating no overall changes in breathing patterns. **Conclusion:** In spite of the long treatment times, no significant changes in respiratory patterns, nor increases in irregular breathing, were observed. This indicates that the long treatment time is not a factor in deciding whether or not gating can be used for patients treated to sites affected by respiratory motion.

SU-FF-J-33

Building a PET Time Series Using Information From 4DCT Data

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Purpose: To build PET time series to be used for radiation treatment planning of lung cancer. Recent advances in time-related treatment strategies call for datasets that account for respiratory motion. Gated PET techniques allow timing information to be used, but suffer from poor signal-to-noise ratio. Non-gated PET images describe the distribution of metabolic activity as a temporal integral over several respiratory cycles. Non-rigid image registration could be used to map this integral representation back to short intervals within the respiratory cycle. **Method and Materials:** CT/PET data were acquired by means of a GE Discovery scanner. 4DCT volumes in different respiratory phases were summed to obtain a volume corresponding to integral PET data. Deformation fields mapping integral CT to single-instant CT volumes were obtained by means of a non-rigid registration algorithm based on a local rigidity regularization method. Results were examined as a function of different regularization parameters. Once a proper value was chosen deformation fields were applied to corresponding PET datasets, obtaining single-instant PET volumes with higher signal-to-noise ratio compared to gated techniques. **Results:** Light regularization parameters caused improbable transformations. In particular, the diaphragm is subject to large global displacement with low spatial frequency. Light regularization may cause high frequency deformations to take place. Optimum weighting factors of the regularization term were found to be between 0.01 and 0.1. **Conclusion:** Multi-modality non-rigid registration is challenging; we avoided it by performing intra-modality registration between CT datasets and by applying obtained deformations to PET data. This strategy may help using PET for treatment planning in 4D treatment modalities. Strategies consisting of penalizing deformations that locally differ from rigidity must be carefully used in thoracic applications. A more suitable approach may consist of a linear combination of low frequency basis functions. Further investigation is needed, including feasibility of on non-uniform control point spacing.

SU-FF-J-34

Can Functional Imaging Be Used to Individualize Adaptive Radiation Therapy for Non-Small Cell Lung Cancer?

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Background/purpose: To determine the changes in tumor and lung function during the course of radiation and their potentials in adaptive radiation therapy for non-small cell lung cancer (NSCLC). **Materials/Methods:** FDG-PET-CT and Ventilation/perfusion (V/Q) SPECT were acquired prior to and after the delivery of 45 Gy during the course of radiation in 15 patients with NSCLC. Tumor activity was measured by relative standard uptake value (RSUV). V/Q SPECT was evaluated blindly by radiobiologist, through comparing to healthy normal controls. **Results:** After 45 Gy radiation, the mean RSUV decreased from 4.6 ± 1.9 to 2.1 ± 1.0 for primary tumors ($p<0.0001$) and from 3.2+1.3 to 1.7+0.5 for nodal diseases ($p=0.0008$). Mean reduction in PET tumor volume was 78% (67-100%). There was 28% (4/15) and 0% (0/15) complete responders on PET and CT, respectively. Three patients achieved a complete CT response at 3 month follow-up, all of them were PET complete responders at 45 Gy. Boosting after 45 Gy, normal tissue complication probability (NTCP) could be reduced by 50%, V20 by 28%, and mean lung dose by 29% while keeping the total dose constant. Keeping the NTCP constant, dose could be escalated by 50%. Lung functional mapping also changed remarkably at 45 Gy during radiation. Fifteen of 15 patients had V/Q defects at or adjacent to tumor on the baseline SPECT, while 14/15 patients had at least one defect located remotely from tumor. For those defects located adjacent to tumor, 79%

improved remarkably, while only 7.9% of the others had notable change ($p<0.001$). Lung NTCP adjusted by V/Q SPECT obtained during radiation was significantly different from those generated from the pretreatment V/Q SPECT and simulating CT. **Conclusions:** Tumor and lung functional imaging during the course of radiation may provide useful information for adaptive radiation therapy in patients with NSCLC.

SU-FF-J-35

Clinical Applications of 3D and 4D Deformable Image Registration for Image Guided Radiotherapy

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Purpose: To develop a framework of 3D and 4D deformable image registration and investigate its applications in image guided radiotherapy (IGRT). **Method and Materials:** We have developed 3D and 4D deformable image registration methods to register fan beam CT (FBCT) and cone beam CT (CBCT) images. Applications of the 3D and 4D deformable registration include: (1) *Inter-subject* atlas-based image segmentation to automatically contour normal tissue regions of interest (ROI) in treatment planning CT images; (2) *Intra-subject* atlas-based image segmentation to delineate daily ROIs by registering daily FBCT or CBCT images to treatment planning CT images. This method is an ideal ROI delineation method for online plan adjustments; (3) 4D deformable image registration to extract average voxel trajectories for real-time tumor tracking and for 4D tomotherapy treatment planning; (4) Deformable fusion of 4D-PET images, which is based on deformable registration of 4D-CT images, to minimize motion blurring in PET images without increase of committed doses or data acquisition time. **Results:** The deformable image registration system was tested using clinical images. Registrations of inter- and intra-subject images show acceptable results. The corresponding results are reported in our supporting document. Quantitative validation of intra-subject atlas-based image segmentation showed agreements with physicians' manual contours. 4D registration yields voxel trajectories smooth in both spatial and temporal spaces. Problems were noticed in the cases where the registration image pairs are intrinsically different, such as gas bubbles in rectums, or deformations are extremely large, such as empty vs. full bladders. **Conclusions:** We have developed a general framework of applying 3D & 4D deformable image registration in image guided radiotherapy. Our clinical applications showed the positive and convincing results.

SU-FF-J-36

Commissioning of a Six-Degree-Of-Freedom Robotic Patient Positioning System in a Proton Gantry

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Purpose: To report on commissioning of a robotic patient positioning system with six degrees of freedom and three digital radiographic panels in a gantry for proton radiotherapy. **Method and Materials:** A new proton gantry with a robotic patient positioner was commissioned in early 2006. The patient positioning "couch" is a Motoman UP200 industrial robot with six degrees of freedom. Image-guided patient positioning is done with three digital radiographic panels and the DIPS software system. DIPS is in use elsewhere, but this was the first time it is used with three X-Ray sources and panels instead of one or two. The beamline and gantry-90 panels are mounted on retractable arms, and an additional gantry-axis panel swings down from above the patient and does not rotate with the gantry. We believe this was the first time an industrial robot was used for patient positioning in a proton gantry. The presentation includes in overview commissioning methods, which involve theodolites, room lasers, and testing with phantoms. **Results:** The patient positioning system meets tight clinical specifications demanded for proton radiotherapy. It is capable of correcting patient position in all six degrees of freedom, namely position in X/Y/Z, pitch, roll, and rotation about the vertical. The first patient treatment with this system will have taken place shortly prior to the 2006 AAPM meeting. **Conclusion:** This patient positioning system is unique, and provides greater degrees of freedom to adjust patient position than conventional ones. It is early to judge its clinical performance just as it comes online, but we are optimistic about the outcome.

SU-FF-J-37

Comparison Between CT-Based and Ultrasound-Based Localization for Prostate Patients

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Purpose: Prostate cancer is often treated with intensity-modulated radiation therapy (IMRT) that provides very steep dose fall-off outside of the target volume and therefore requires precise alignment. In this report, we compare ultrasound (U/S) and CT localization, and evaluate the uncertainties of the two modalities. **Method and Materials:** A total of 19 prostate patients (275 alignments) were included in the study. The prostate was localized with the BAT U/S system (Nomos, Cranberry, PA). CT scans were performed with the Primatom CT-on-Rails system (Siemens, Concord, CA). The two alignment techniques were identical: the simulation contours of the prostate, proximal seminal vesicles, bladder, and rectum were aligned with a pre-treatment image. The random uncertainty of the CT system was estimated based on intra-user variability, and a simple mathematical model of the motion of radio-opaque markers. Then the random error of the ultrasound alone was calculated. **Results:** The systematic differences between (U/S) and CT alignments were (in mm): 0.3 (lateral), 0.4 (AP) and 0.3 (longitudinal). The random differences between the two modalities (one standard deviation) were (in mm): 2.2 (lateral), 2.2 (AP) and 2.4 (longitudinal). The estimated ranges of random uncertainties of the CT alignments (one standard deviation) were (in mm): 0.9 to 1.2 (lateral), 0.7 to 1 (AP), and 1.2 to 1.5 (longitudinal). Based on these results, the calculated ranges of random uncertainties of the U/S alignments were (in mm): 1.8 to 2.0 (lateral), 2.0 to 2.1 (AP), and 1.9 to 2.1 (longitudinal). **Conclusion:** There was a strong correlation between the extent of prostate inter-fraction alignments using ultrasound and CT. The localization of the prostate had a total uncertainty (two standard deviations) of 2 to 3 mm when using the Primatom CT-on-Rails and around 4 mm when using the BAT system.

SU-FF-J-38

Comparison of Different Image-Guided Setups for Radiotherapy of Prostate Cancer

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Purpose: To compare different methods of image-guided daily setup for prostate cancer treatment. **Method and Materials:** 10 CTs were acquired on non-consecutive treatment days for 20 patients receiving radiation therapy of their prostate cancer under an IRB approved protocol. One physician contoured the prostate, rectum and bladder for all scans. 3 different patient setup methods were compared dosimetrically: 1) laser-skin mark alignment; 2) 2D bony landmark alignment; and 3) prostate center-of-mass alignment. A commercial planning system (Panther, Prowess, Inc.) based on the Direct Aperture Optimization was used for the initial and subsequent planning and analysis. For each patient, the original plan using the first CT set was copied to the subsequent 9 CT sets in 3 different ways based on the setup methods. Dose distributions and DVHs were compared using simple averaging of 9 samples. **Results:** So far we have completed the analyses for 6 patients. Average patient shifts needed after laser alignment were: Left-Right(Lt-Rt): 0.37±0.27cm, Superior-Inferior(Sup-Inf): 0.33±0.25cm and AP-PA: 0.08±0.09cm with bony landmark-based alignments. The shifts based on the center of mass were: Lt-Rt: 0.4±0.29cm, Sup-Inf: 0.08±0.11cm and AP-PA: 0.2±0.21cm. Three measures were used for the comparisons: 1)PTV getting the prescription dose of 75.6Gy; 2) rectal volume getting 60Gy; and 3) bladder volume getting 65Gy. These measures averaged 100%, 13.2% and 16.6% in the original plans. With lasers alignment, these measured changed to 88%, 17.0% and 20.7% respectively. With 2D bony landmark alignment, these three measures were 90.3%, 20.9%and 24.8% respectively. With volumetric image guidance, they were 93.0%, 16.6%, and 17.8% respectively. **Conclusion:** Significant plan degradations by reducing target coverage (up to 12%) and increasing normal tissues dose were observed with conventional skin mark-based alignment. Daily bony landmark-based setup only improved marginally. Rigid-body volumetric alignment of the PTV showed the least degradation of the original plan.

SU-FF-J-39

Comparison of Patient Positioning Corrections For Prostate IMRT Patients Using Competing Image Guided Radiation Therapy Technologies

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We compared prostate position corrections using ultrasound and megavoltage CT image guided systems following initial patient positioning with lasers. Internal prostate movements between the two patient cohorts were assumed to be equivalent given a sufficient number of measurements, so we hypothesize the image guided shifts should average out to the same magnitude. Therapists adjusted patient positions with physician supervision based on daily imaging prior to each treatment. A total of 17 prostate patients were studied. Ten patients (Group I) were scanned in 3-D mode using an ultrasound system. Contours (prostate/bladder/rectum) from the treatment planning system were transposed on the image set to register the ultrasound image. Therapists shift the contours to match the ultrasound image set and then adjust the patient by these same shifts. The number of shifts recorded from Group I was 432. Group II patients (seven subjects yielding 315 recorded shifts) were treated using Tomotherapy. Patients were scanned over the prostate region and the megavoltage CT image was registered with the treatment planning CT and contours. Shifts were produced for each axes and in roll. The patient table is adjusted to match the registration shifts. Roll corrections were minor and deemed insignificant for this study. The average prostate size from Group I was 104.9cc with a standard deviation of 42.1cc while Group II was 104.2cc and 54.8cc. A panel of four was formed to evaluate the quality of images to check possible operator bias due to image quality. Group I showed an average shift magnitude of 6.1mm with a standard deviation of 3.4mm. The average shift from Group II was 10.6mm with a standard deviation of 6.1mm. Tomotherapy imaging averaged 43% larger shifts compared to ultrasound. Possible explanations for this difference include operator laxity in initial tomotherapy positioning while depending on imaging and auto-adjustment to compensate.

SU-FF-J-40

Comparison of Prostate Implanted Fiducials with CT and Ultrasound for Prostate Target Localization: Initial Results

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Purpose: To compare prostate localization methods of implanted fiducials, CT-guided, and ultrasound-guided (US) techniques. **Method and Materials:** Data were collected from an on-going institutional review board approved protocol for comparing different target localization techniques for image-guided prostate cancer radiotherapy. The protocol is designed to have CT scans with an in-room CT-on-rails three times a week; US-guided localization twice a week for the initial two weeks, then weekly; and orthogonal electronic portal imaging for fiducial measurements daily. Patients will have three gold seed implanted fiducials for prostate localization. The NOMOS BAT system and MedTec's Acculoc software are used for US and fiducial localization, respectively. All shifts reported by the three methods are relative to the same daily reference point set on patient's skin during the entire imaging session. The differences in the three methods were compared and the mean and standard deviation were computed in each of the orthogonal shifted positions: anterior-posterior (AP), superior-inferior (SI), and laterals (RL). Correlation coefficients were determined relative to the CT localization method. **Results:** We report the results for the first patient who had just completed treatment. The mean differences (one standard deviation) (in cm) between the implanted fiducials and CT were -0.03 (0.18), 0.0 (0.12), -0.03 (0.15), while US and CT were 0.14 (0.68), -0.21 (0.68), and 0.32 (0.28), in AP, SI, and RL directions, respectively. The Spearman's correlation coefficients relative to the CT registration were 0.83, 0.60, and 0.81 for the implanted fiducial method ($p<0.003$ for all directions) and -0.18, -0.09, and 0.90 for the US localization technique ($p>0.05$ for AP and SI directions). Note that simultaneous measurements were 22 for CT and fiducials while only 9 for CT and US. **Conclusions:** Implanted fiducial registration correlates better than the US relative to the CT-guided approach. More patients are needed to make a firm conclusion.

SU-FF-J-41

Comparison of Various Respiration Measurement Methods for 4D Radiotherapy

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Purpose: To find the best method corresponding with respiratory target motion, ten patients' respiratory patterns were measured by various methods simultaneously. Respective respiration monitoring methods were compared with fluoroscopic target motion during simulation. **Method and Materials:** A respiration monitoring system using thermocouple was developed to measure patient's respiration. Conventional spirometer and home made thermocouple were connected to a mouse piece to measure the patient's respiration simultaneously. A respiration acquisition program was built by using Labview 7.0 (National Instruments, Austin, TX), which acquire respiration signals and display its patterns. A fluoroscopic target tracking program was built by using IDL 6.1 (Research Systems, Inc, Boulder, CO). Ten patients with lung or liver cancer participated in this study. Fluoroscopic movies were captured during acquisition of their respiration patterns. At the same time their skin motion was measured by using Real-time Position Management® (RPM®, Varian, Palo Alto, CA) system. Respiratory patterns from spirometer, thermocouple, and RPM® system were compared with fluoroscopic target motion respectively. Its relationships were evaluated as correlation coefficient. **Results:** Comparing each correlation coefficient for spirometer, thermocouple, and RPM®, skin motion detection is the most correspondent with fluoroscopic target motion. However, respiration monitoring methods with spirometer or thermocouple also correlate well (more than 0.9). **Conclusion:** Respiratory pattern depends on a patient and his/her conditions. The relationship between thermocouple and fluoroscopic target motion could be enhanced by correlating respiratory signal with target motion. Respiration monitoring methods with spirometer or thermocouple, and skin motion detection are feasible to monitor the target motion for applying 4D radiotherapy.

SU-FF-J-42

Cone Beam CT Based Treatment Planning

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Purpose: To evaluate treatment planning based on cone beam CT (CBCT) using latest software on a LINAC 21IX CBCT imaging system. **Method and Materials:** An anthropomorphic chest phantom having bone, soft tissue, and lung components was used to create and evaluate treatment plans based on conventional CT and CBCT images. Conventional CT images of 2.5 mm slice thickness were taken with a GE discovery LS CT/PET system. CBCT images slices were also reconstructed from flat panel system on a Varian LINAC 21IX. Eclipse treatment planning system was used to compare treatment plans from the conventional CT and CBCT images. The AAA algorithm was used in the treatment planning system for inhomogeneity correction. Regions of interest around the bone, soft tissue, and lung in both CT and CBCT images using identical HU threshold values were drawn. Identical targets located in the lung were used in each treatment plan. Analysis of the treatment plans was performed by comparison of geometrical dimensions, total volumes and dose volume histograms of the target and regions of interest. **Results:** Geometric comparison of actual external spatial dimensions and others in lung and bone were found to be within 1 mm. Volumetric comparison of the regions of interest resulted in a 2.8% difference of the vertebrae, 3.3% of the right lung, and 3.7% of the total external volume. Dosimetric results show similar dose distributions. Dose volume histograms are also comparable. **Conclusion:** Results demonstrate that treatment planning based on CBCT is feasible. Plans created from CBCT images are comparable to plans created with conventional CT systems. **Conflict of Interest:** Partly funded by Prostate Cancer Foundation grant UW 133-HR30.

SU-FF-J-43

Correlation Between External Abdominal and Internal Liver Fiducial Motion in 4D-CT

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Purpose: to determine how well the anterior-posterior location of a marker, placed on a supine patient's abdominal surface, correlates with the location of a radio-opaque fiducial implanted within the liver. We investigate which respiratory phases exhibit the best correlation between the marker and the fiducial. Methods and Materials: data was obtained from five patients, each having a fiducial (either an implanted gold pellet or the tip of a stent) in the liver. Each patient received a cine-mode 4D-CT scan of the liver, with the position of an external marker used to associate each cine CT image with a specific respiratory phase. The trace of the anterior-posterior motion of the marker was normalized under the assumption that, among ten phases of a full respiratory cycle (0%, 10%, 20% … 90%), the marker displacements correlated linearly with the fiducial's superior-inferior displacements. Each cycle of the normalized marker trace was then superimposed upon a plot of the fiducial's displacement; the latter was measured within the 4D-CT data set for each of the ten phases. **Results:** comparisons of the marker trace and the fiducial coordinate from 4D-CT indicated that, in general, the marker motion correlated reasonably well with internal liver motion during the process of exhalation (from end-inspiration to end-expiration), with optimum correlation during end-expiration (40% to 60% phase). The correlation tends to be poorer during inhalation, extending from 70% to 90% phase. **Conclusions:** a tight correlation near end-expiration suggests that using an external-motion-based respiratory trace, as a guide for gated treatments for liver cancer, should enable reliable and reproducible coverage of the target volume. Poorer correlation during inhalation suggests that the marker's anterior-posterior motion may not adequately characterize the internal motion during those phases, and that gating should be avoided during this stage of the respiratory cycle.

SU-FF-J-44

Daily 3D On-Line Setup Verification and Correction for 45 Prostate Patients Using Implanted Gold Markers

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Purpose: To minimize the CTV-PTV margin by correcting for prostate motion and positioning during external beam therapy using implanted gold markers and a 3D on-line correction protocol. **Method and Materials:** 45 patients had four gold markers (1x7 mm) implanted in their prostate. They are inserted under ultra sound guidance by an urologist using a standard prostate biopsy tool. The beams eye view projection of the markers is outlined in the DRR's. Patients are treated with a three field technique. For each treatment session four images are acquired with a Theraview NT or Iview GT EPID and stored in a central database. First 5MU of the AP and 10MU of the LL beam are delivered. While the patient is on the couch, templates of the reference images are matched with the MV images. For shifts $\geq$2 mm the technician enters the treatment room and moves the couch. Then the rest of the treatment is delivered and images are acquired of the LL and AP beam. These images were analyzed and the effect of using the NAL protocol or no correction was simulated. **Results:** The systematic (random) ($\Sigma(\sigma)$) variation was reduced in lateral, cranial-caudal and AP direction to respectively 0.6 (1.1), 0.6 (1.1), 0.5(1.6) mm, compared to 1.3(1.7), 1.4(1.9), 1.8(2.5) mm when using the NAL protocol and 2.2, 2.4, 3.5 mm without correction. Based on these results we reduced, after treating 10 patients, the CTV-PTV margin to 6 mm in all directions and increased the dose to the prostate from 74 to 78 Gy. The whole procedure could be done in a standard 10 minute treatment slot. To reduce the workload remote couch steering is currently being tested in cooperation with the linac manufacturer. **Conclusion:** Using a simple and effective method the CTV-PTV margin was reduced to 6 mm in all directions.

SU-FF-J-45

Daily Changes in Seminal Vesicle Location During Treatment of Prostate Carcinoma

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Purpose: In this study we examined daily bladder filling variation and the effect it has on seminal vesicle (SV) location on patients treated for high-grade prostate carcinoma. Currently there are several methods of image-guided radiotherapy (IGRT) used to locate the prostate on a daily basis. These methods, however, do not account for the change in position of the SVs, relative to the prostate, determined during simulation (day 0). Using this displacement information, we would like to determine if our clinical SV PTV margin is adequate. **Method and Materials:** To determine SV displacement, 496 daily sagittal ultrasound images (BAT, North American Scientific, Chatsworth, CA) from 18 patients were examined. The images provided sagittal outlines of the day-0 structures overlaid on the daily patient ultrasound. With the day-0 prostate aligned to the day-n prostate ultrasound image, differences between day-0 and day-n bladder and SVs positions can be determined. SV displacement was taken at the mid point of the SV. The change in bladder position was determined by the difference in posterior extent anterior to the SVs. **Results:** The SV displacement population mean and standard deviation (SD) was 2.1 mm 2.8 mm respectively. The bladder displacement population mean and SD was 2.7 mm and 3.3 mm respectively. The maximum SV displacement for all patients was 2.5 cm. The maximum SV and bladder displacement SD for any one patient was 7.4 mm and 7.7 mm respectively. **Conclusions:** The results show that in general typical SV motion is quite small averaged over a standard treatment course. Since the population SD is small, our 8 mm SV PTV is adequate using daily prostate alignment. There are however some patients who's SV location changes are substantial on a day to day basis given a SD of 7.4 mm. Consistent bladder filling may be critical when treating SVs.

SU-FF-J-46

Determination and Validation of a 4D Trajectory for Respiration-Induced Real-Time Tumor Motion Tracking

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Purpose: To model the tumor trajectory non-invasively by modeling the instantaneous tumor position using the "average" tumor position derived from a 4D CT scan. A real-time motion-synchronized idealized moving treatment couch was used to validate the trajectory dosimetrically. Methods and Materials: In this study, we consider data from 7 patients who underwent a 4D CT scan – 5 lung tumors and 2 pancreas tumors. The CT images were retrospectively sorted according to phase, and the tumor contoured by a physician. The tumor's trajectory was modeled parametrically, using a 5-term Fourier series to fit individual coordinate trajectories. These were then combined to yield a continuous 3D tumor trajectory. Compensation of this trajectory was modeled using a moving treatment couch with idealized dynamics. To validate the compensation, both a 7-beam conformal plan, and a 7-beam IMRT plan were ran for both the original and compensated tumor volumes for each patient. **Results:** The RMS residual error for the fitted trajectories averaged 0.41 ± 0.22 mm, with a corresponding average tumor motion amplitude of 9.7 ± 5.3 mm. For patients with motion amplitudes greater than 5 mm, the average improvement in the 100% dose coverage between end-inhale and end-exhale was 24.3% for the 3D conformal plan, and 31.1% for the IMRT plan. Tumors with motion amplitudes less than 4 mm saw improvements in the 100% dose coverage of less than 1% for 3D conformal plans, and 8.2% for IMRT plans. **Conclusion:** High-resolution tumor trajectories can be established with a 4D CT scan, and the tumor position can be sampled at a rate comparable to fluoroscopy tracking of implanted markers. Tracking and compensation using this technique has been shown to greatly improve the dose coverage and conformality for both 3D conformal and IMRT plans in comparison.

SU-FF-J-47

Determination of Internal Target Volume Reconstruction Algorithm Beyond the Time Dimension Using Second Model of a 256-Slice CT

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To observing trajectory of moving tumor under free breathing, we compared two image-processing methods and two reconstruction algorithms based on the FDK and adapted to the 256-slice CT. These algorithms were namely 4D image average (4DIA) and 4D image maximum intensity projection (4DIM), 4D projection data average (4DPA) and 4D projection data maximum intensity projection (4DPM). The concept of 4DIA and 4DIM was generated on CT image after backprojection process. 4DIA was averaged each pixel value on the volumetric CT data along the time axis, and 4DIM was selected maximum each pixel value along the time axis. With regard to the 4DPA and 4DPM, these essential concepts are to process projection data along the time axis, rather than reconstructed CT images as 4DIA and 4DIM.
Evaluations of these algorithms were done in the image noise, CT-number accuracy, and target moving distance with various reconstruction time conditions using lung cancer patients and compared these results with those with volumetric cine images. As the results, it is difficult to observe the edge of the tumor in 4DIA and 4DPA images due to decreasing CT number from the original tumor CT number. While 4DIM images emphasized pulmonary vessels as increasing the processing time ranges and it makes difficult to observe the accurate tumor edge. From these results, 4DPM provides the accurate tumor movement and accurate CT-number independent of the reconstruction conditions.

SU-FF-J-48

Developing In-Line KV Fluoroscopic Verification for 4D Adaptive Radiotherapy

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Purpose: To develop a system for on-line real-time treatment verification for 4D-ART using in-line kV fluoroscopy that will be included in a new generation of accelerator. **Method and Materials:** We have developed a software tool, as a component of the 4D-ART verification system, to register fluoroscopic with dynamic (time-sequenced) DRR (DDRR) images. The fluoroscopic images are obtained using kV x-rays in-line with the treatment-beam direction. The DDRR images (DRRs at different phases during respiratory cycle) are generated from 4DCT. The image registration of DDRR and fluoroscopy is based on pre-defined structures or points of interest and needs to be performed on-line in real time, allowing the treatment parameters to be modified in real time if a discrepancy is observed. To approve the principle, we have employed a simulator (Siemens/Mevasim) to acquire the fluoroscopic images. Both hardware and software tools were developed to synchronize the acquisition of fluoroscopy with respiratory signal using a pressure sensor (Anzai). This synchronization, in turn, harmonizes fluoroscopic images with DDRR. The verification system was tested on a motion phantom and on lung cancer cases. **Results:** The system developed can effectively register respiration-synchronized fluoroscopic and DDRR images for both phantom and patient data. The registration is able to detect discrepancies between planning images (DDRR) and verification images (in-line fluoroscopy) for a 4D-ART delivery. The system is found to be effective for validating respiratory gating. **Conclusion:** We have developed a treatment verification system for 4D-ART. The system, employing in-line kV fluoroscopy, may be used for validating respiratory gating and for 4D-ART with the new generation of image-guided delivery machine capable of in-line dynamic imaging. The system can be also potentially useful for 4D real-time tumor tracking based on fluoroscopy. **Conflict of Interest:** This work is supported in part by Siemens OCS.

SU-FF-J-49

Dose Comparsion of MVCB and Orthogonal Pair Portal Images

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Purpose: To evaluate the delivered patient doses resulting from MVCB(Mega-Voltage Cone Beam)and ORTH(orthogonal pairs)portal imaging techniques, and report dose per MU(cGy/MU)and absolute dose(cGy)at isocenter, max dose,and mean doses to the target and critical organs. **Method and Material:** Both image techniques are based on a Siemens 6 MV LINAC equipped with an A-Si flat panel and dose calculation done on a Pinnacle 3DRTP system.The ORTH technique was simulated by two orthogonal beams,total 6 MUs and 20cmx20cm field size.The MVCB technique was delivered with a 200° arc beam, total 9 MUs and the same field size.30 patients representing 6 treatment sites were analyzed.Calculated doses were reported for max dose in patient,dose at the isocenter, and mean doses to target and critical organs. **Results:** For the cGy/MU analysis, the value at isocenter was similar.The difference of max dose was greater in pelvis and abdomen.The mean dose in normal lung or contralateral breast differed greater than other critical organs.In contrast,the dose difference in the target or critical organs close to isocenter was very small.The absolute dose difference and 2D absolute dose distributions are shown.The high dose area for ORTH technique is located at the proximal corner of rectangular areas intersected by the two beams but anteriorly for MVCB due to the anterior arc,and contributes more dose to anterior organs like normal lung and contralateral breast. **Conclusions:** From our analysis,high dose region generated by MVCB is shown inside the critical organs,and tends to be larger compared to the ORTH technique.Due to the potential biological effects,the extra dose burden to the critical structures should be monitored carefully.This study provides a quantitative analysis and suggests the number of projections and total MUs are the most important factors for the MVCB technique.

SU-FF-J-50

Dose Guidance in Radio Therapy by Means of Entrance Dosimetry

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Purpose: Recently, we introduced a novel hardware design for an image and dose guidance in radiation therapy. An in-line cone-beam CT was integrated on a Siemens linear accelerator providing a radiographic localisation of bone and soft-tissue targets and an on-line in vivo 3D reconstruction of delivered dose. In this presentation we focus on the aspect of dose guidance. We will present a new developed method of 3D in vivo dosimetry and the first clinical results. **Method and Materials:** A flat-panel detector RIDXXX (Perkin Elmer) is mounted at the Linac head, in front of the patient. The flat-panel was calibrated against a film measurement to consider off-axis variations of the photon spectrum. Images of each therapy beam were recorded by the flat-panel during beam delivery and beside dark correction each measured image was de-convoluted using an empirically derived scatter kernel resulting in a 2D distribution of the primary photon fluence which is comparable with the TPS fluence. As a final step the measured fluence distribution for each IMRT beam was fed into the TPS in order to reconstruct the delivered dose distribution in 3D. This method of entrance dosimetry was applied to 12 patients. **Results:** A generally good agreement of planned and reconstructed dose distribution was also seen for all patients. The error was calculated to be less than +/- 3% for all cases and a very good reproduction of all isodose contours was achieved, with agreement to within +/- 1mm in most places. **Conclusion:** A new method of 3D in vivo dosimetry called “Entrance Dosimetry” was developed. This kind of 3D in-vivo dosimetry can be used for an off-line treatment plan verification and for dose guidance by means of an on-line delivered beam verification as well. **Conflict of Interest:** This work was partly supported by Siemens OCS

SU-FF-J-51

Dosimetric Evaluations of Organs at Risk for Head and Neck Cancer Patients During Entire IMRT Treatment Course

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Purpose: Significant anatomic changes occur during radiotherapy treatment course for head and neck cancer patients. The purpose of this study is to evaluate the dosimetric changes by estimating the cumulative doses to critical organs. The finding will help better understand the uncertainties in initial plans and decisions making for replanning. **Method and Materials:** Patients treated with IMRT at our institution are immobilized on MedTec IPPS for simulation, CT and treatment. Guidelines from RTOG protocol are followed in defining target and organs at risk (OAR) volumes. Weekly helical CTs are acquired and fused to planning CT based on bony anatomy. Therefore, effect of setup error is excluded. OARs are delineated by a single physician manually on each CT. Dose distributions are recomputed for each CT using same beams from initial plan. Dose is evaluated for each CT and cumulative dose is estimated and compared with the original plan. **Results:** Up to 10% reduction on skin volume is observed for a single patient. However the average reduction is only 2%, because bony structures are fairly stable and shrinkage only occurs in soft tissues. The cumulative maximum doses to cord, brainstem and mandible, expressed as the ratio to initial plan, are 1.00±0.03, 1.01±0.08, and 1.01±0.08 respectively. The changes are minimal. For parotid glands, mean dose and V_{30} (volume to 30 Gy) can be increased by 10%, with up to 20% for a single patient. This is because parotid gland tends to move into the center of the field. **Conclusion:** Repeated CT scans during treatment course allow more accurate evaluations of the dose distributions, which can be significantly different from original plan due to radiation response of tumor and soft tissue. The cumulative doses are more reliable in describing the actual doses delivered and can be used for correlative studies with clinical results.

SU-FF-J-52

Dosimetric Impact by Temporal Changes of the GTV in Head and Neck Cancers

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Purpose: Over a 6 week head and neck cancer treatment course, radiation and chemotherapy induce considerable changes in the volume and geometry of the tumor and normal tissues. When using highly conformal radiotherapy, even relatively small changes in the tumor volume could alter target coverage and possibly the therapeutic efficacy. The purpose of this study is to investigate the dosimetric impact of anatomic changes during the treatment course. **Method and Materials:** A representative patient with nasopharynx cancer treated with IMRT was studied. Cone beam CT scans covering the skull base and upper neck were acquired at the beginning and after every 10 treatment fractions. The GTV was contoured on the initial treatment planning CT scan and recontoured on subsequent CBCT scans to reflect treatment-related changes over time. Radiation dose was recalculated on each CBCT using the same treatment isocenter and the original IMRT fields, MLC sequences, and monitor units. The GTV DVH's were compared to assess changes in tumor coverage. **Results:** Somewhat counterintuitively, GTV coverage decreased over time as the tumor volume decreased. GTV volume decreased by 15% after 10 fractions and 40% after 20 fractions. Conversely, 100% of the prescribed dose covered 95% of the GTV initially, 80% after 10 fractions, and 74% after 20 fractions. **Conclusion:** These results show that temporal changes in tumor volume and geometry can have a potentially clinically significant effect on the dosimetry. The decreasing GTV coverage over time implies the need to re-evaluate the treatment plan during the course of treatment and incorporate changes necessary to achieve adequate tumor coverage.

SU-FF-J-53

Effect of Tumor Motion On the Use of PET Images for Target Volume Delineation in Radiation Treatment Planning

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Purpose: To assess the effect of both motion and medium heterogeneity on automatic PET target delineation fused with CT images for radiation treatment planning of lung tumors. **Method and Materials:** The data were acquired on Philips Gemini PET-CT scanner. A movable lung phantom was built using the NEMA IEC body phantom containing 6 hollow spheres with diameters ranging from 10 to 37 mm. The phantom volume was packed with Styrofoam beads and filled with water to reach the density close to the density of lung 0.3g/cc. The tumor motion was simulated by a movable acrylic table that provided variable amplitudes and frequencies of movement to the phantom. The spheres were filled with 1.14 mCi/ml of FDG. There was no background activity in the body phantom outside of the spheres. Scans were performed for variable amplitudes ranging from 0.5 to 2 cm. CT and PET images were auto-contoured on Pinnacle workstation using variable thresholds relative to the maximum SUV. The threshold that best measured the volume of each sphere in static mode and the effective volume in dynamic mode was assessed. **Results:** The SUV threshold that best defines the target volume in static mode and the effective volume in dynamic mode when no respiratory gating is applied depends on the motion amplitude. The small spheres are more sensitive to the inhomogeneity of the medium, most probably because the positron range is greater in lung equivalent medium then in water. **Conclusions:** The study shows that it is not accurate to apply a constant threshold for target volume delineation in radiation therapy for all tumor sizes and variable tumor movement. The change of target delineation threshold is more due to the increase of the partial volume effect when the tumor activity is spread over a large volume proportional to the magnitude of movement.

SU-FF-J-54

Effectiveness of 4D CT On Stereotactic Radiosurgery of Lung Cancer

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Purpose: In order to spare the normal tissues as much as possible during stereotactic radiosurgey (SRS) of lung cancer by limiting the tumor motion within 5 mm, 4D CT was implemented and its usefulness was evaluated. By comparing CT during the simulation with CT during the treatment, the interfractioanl positioning errors were assessed and image guided radiotherapy was performed using the images from ExacTrac x-ray system (BrainLab, Germany) in the treatment room. **Method and Materials:** For 11 lung cancer patients positioned in the SRS frame, 4D CT was acquired and treatment was planned based on 4D CT. For the patients whose tumor motion was larger, the motion was controlled to be less than 5 mm using the real-time positioning management (RPM, Varian, USA) system. To verify the interfractional patient positioning errors, CT was acquired twice during the course of treatment and ExacTrac x-ray system was used to reproduce the patients' setup. **Results:** From the 4D CT, mean GTV and PTV were 15.9±9.6 cc and 40.7±16.6 cc, respectively. Tumor motions were 2.9±1.4 mm, 3.4±3.2 mm, and 12.1±5.0 mm in lateral, vertical, and longitudinal direction, respectively, for the full respiratory phases, which were reduced to 3.7±1.1 mm during 30 ~ 70 % phases selected for the gated radiotherapy. Discrepancy between planning CT and two CT during treatment was 1.2±1.0 mm, 1.4±1.2 mm, and 2.3±1.5 mm, and setup errors from ExacTrac system were 1.0±1.8 mm, -0.3±2.2 mm, and -0.6±3.2 mm in lateral, vertical, and longitudinal direction, respectively. **Conclusion:** The use of 4D CT, the repeated CT scans during treatment, and image-guided technique using x-ray imaging system in treatment room for setup correction was effectively implemented for SRS of lung cancer, which assured the tumor motion and positioning errors within 5 mm during treatment.

SU-FF-J-55

Effects of Motion On Cone Beam CT Image Quality

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Purpose: On-board cone-beam imaging is being used to collect kilovoltage CT images for treatment position verification and analysis of tumor response. One challenge of cone-beam imaging is that full sinogram acquisition takes more than 1 minute. While breathing motion in the lungs, influence both cone-beam and fan-beam modalities, its profound effects in cone-beam CT are well known. However, there are many portions of the body where voluntary and involuntary processes can yield small motions. The purpose of this study is to investigate the influence of small motions on cone-beam reconstruction quality. **Materials and Methods:** A commercial CT performance phantom (Catphan, Phantom Laboratory, Salem, NY) containing various image quality assessment tools was imaged using a kilovoltage on-board cone-beam CT system (Varian Medical Systems, Palo Alto). The imaging phantom was moved using an in-house developed "4D phantom" (with a 0.4 mm position accuracy), in sinusoidal patterns with amplitudes of 1.25mm and 2.5 mm in the three orthogonal directions and elliptical patterns with axes from 1 mm to 2.5 mm in steps of 0.5 mm. To quantify the effect on the image quality, the CT number accuracy, spatial integrity, image uniformity, high and low contrast resolution were compared. **Results:** CT number accuracy and spatial linearity were unaffected by motion. While single-dimensional motion did not affect the low-contrast resolution, elliptical motion yielded degradation. The visibility of the 1% cylindrical low contrast resolution targets was 7 mm, 8 mm and 15 mm for static through 1 mm, 2.0 mm, and 2.5 mm ellipses. High contrast spatial resolution was improved slightly for in-plane motion, but degraded sharply with out-of-plane motion. **Conclusions:** This information will allow investigators to evaluate the ultimate utility of cone-beam imaging for imaging studies when patient immobilization is not perfect.

SU-FF-J-56

Estimation of Lung Tumor Setup Uncertainties Using Bony Landmarks and Implanted Fiducials

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Introduction: Setup uncertainties require margins to be placed around the internal target volume (ITV) so that the tumor stays within the treatment portal during the course of treatment. The purpose of this work is to estimate setup uncertainties for lung tumors using both bony anatomy and implanted fiducials as surrogates for tumor position. **Methods and Materials:** Fiducials were implanted in the periphery of lung tumors of 4 patients who were treated using respiratory gating. Setup uncertainties were quantified using the fiducials in the gated images (acquired from the electronic portal imaging device (EPID) operated in cine mode) each day, using the fiducials in the repeat 4D image acquisitions, using the bony anatomy in the repeat 4D image acquisitions. Standard deviation (SD) of population systematic uncertainty (Σ), and SD of random uncertainty (σ) were determined (in cm) from each patient's mean systematic and random setup uncertainties. **Results;** For the Left/Right (LR), Superior/Inferior (SI), Anterior/Posterior (AP) directions, respectively, using implanted fiducials during treatment, Σ was 0.41, 0.70, 0.47, and σ was 0.34, 0.45, 0.43. For the LR, SI, and AP directions measured using implanted fiducials on the repeat 4DCTs, Σ was 0.26, 0.26, 0.42, and σ was 0.29, 0.27, 0.45. For the LR, SI, and AP directions measured using bony anatomy on the repeat 4DCTs, Σ was 0.08, 0.36, 0.27, and σ was 0.24, 0.33, 0.43. **Conclusions.** We were able to quantify setup uncertainties using two surrogates for lung tumors using repeat 4DCT image acquisitions and gated EPID images. The SD of the systematic and random components of setup uncertainties varied up to 4.5 mm as measured on 4DCT and up to 7 mm as measured on EPID images suggesting that setup uncertainties can be significant.

SU-FF-J-57

Evaluating Lung Motion Variations in Repeated 4D CT Studies Using Inverse Consistent Image Registration

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Purpose: To evaluate lung motion variations in repeated, amplitude-based 4D CT studies using inverse consistent image registration. **Method and Materials:** Three patients with lung cancers were scanned twice with our 4D CT protocol. A 4D CT dataset was reconstructed using the amplitude and direction of an external respiratory signal. A thresholding-based method was used to segment the lung. An inverse consistent image registration was used to estimate the intrafraction motion within each 4D study and the interfraction motion between two studies. This diffeomorphic registration jointly estimates the forward and reverse transformations providing more accurate correspondence between two images. We evaluated the lung motion variations in repeated 4D studies. **Results:** On average, the mean respiratory period changed by 11.5%, and the mean peak to peak amplitude changed by 6.8% for the three patients. The consistent image registration generated dense displacement vector fields which represented physiologically reasonable lung motion. In one patient, we observed that the motion patterns are similar in the inferior and posterior parts of the lung, but are different at the superior and anterior parts of the lung. In the other two patients, we observed less variation in lung motion patterns between the two studies. The interfraction motion at end of exhalation is generally small (< 3 mm). **Conclusions:** The results suggest that lung motion variation may be large for some parts of the lung in some patients. An updated 4D CT study may be needed on a treatment day for some patients. For other patients, one may use the 4D model built on a planning day to estimate lung motion with an external respiratory signal. Quantitative evaluations are under investigation.

SU-FF-J-58

Evaluation of Immobilization Devices Using EPID Measurements of Patient Set Up Variations

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Purpose: Methodology to evaluate the performance of immobilization devices for head and neck (H&N) treatments using EPID measurements and a multiple linear regression model. **Method and Materials:** The immobilization devices considered for the analysis were: UON™ mask, Type-S™ and Bear Claw™ head/neck/shoulder systems. We acquired daily electronic portal images for 35 H&N patients. PortalVision™ software was used to perform anatomy matches using the Digital Reconstructed Radiograph from the CT-simulation, as the matching anatomy reference. The two-dimensional mismatch data decomposed into the appropriate components along each body axis and the orientation of the patient, gantry and couch angles were considered. In order to evaluate the impact of the immobilization device on the deviation of a particular reference structure between simulation and treatment, we used a multiple linear regression model. **Results:** Although the mean values of the estimators are adequately estimated under the simple statistical procedures, the standard deviations of those estimators will be biased due to the clustered nature of data. The biasness in standard deviations will invalidate the T- and F-tests. In order to correct for biasness of the standard deviations, we used a linear regression approach to generate robust standard errors corrected for clustering. We compared the results of an uncorrected linear regression with the corrected ones. Even though the uncorrected model showed statistically significant impact of using a particular device on the mean of the variation, the significance is eliminated when using corrected standard errors. **Conclusion:** By correcting for clustered and heteroscedastic nature of the data in a multiple regression setting, we assessed the degree of inter-fractional variation and concluded that it is independent of the immobilization method. The effect of other factors (i.e. patient characteristics, experience of staff) on mean deviation may need to be considered for further analysis. **Conflict of Interest:** Partially funded by Varian.

SU-FF-J-59

Evaluation of Segmenting Anatomical Sub-Regions for Deformable Registration of Patient Lung 4DCT

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Purpose: To evaluate the advantages of segmenting the moving and less-moving tissues for deformable registration of lung 4DCT data. **Method and Materials:** Deformable registration based on B-spline optimization is used to register lung 4DCT data from end-inhalation to end-exhalation phase. The moving tissues (lungs, mediastinum, and abdomen) and less-moving tissues (the rest) are segmented at each respiratory phase. Deformable registration between phases was conducted in two different ways and compared. The first method registers the entire CT volume at once. The other method registers the moving and less-moving tissues separately, and merges the resultant vector fields together. **Results:** The performance of the registration methods with and without segmentation was evaluated on two lung 4DCT data sets. The deformation vector field near the chest wall as generated by the registration with segmentation demonstrates a discontinuity of deformation along the plural interface. Quantitative analysis shows that the vector fields produced by the two methods are comparable in most of the areas, but have significant differences along the plural interface. **Conclusion:** Our experiments suggest that registering the anatomical sub-regions separately allows the registration to properly account for motion discontinuity along the plural interface. While the two methods produce similar overall warping, the segmentation will generate a more realistic registration in the vicinity of the plural interface. **Conflict of Interest:** research was supported in part by Varian Medical Systems.

SU-FF-J-60

Evaluation of the Three Dimensional Localization Accuracy Using Cone-Beam Computed Tomography of Varian On-Board Imager (OBI)

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Purpose: To evaluate 3 dimensional (3D) localization accuracy using cone-beam computed tomography of a Varian On-Board Imager (OBI) in a phantom study. M**ethods and Material:** An anthromorphic pelvic phantom was used to simulate an actual patient positioning scenario. The possible patient shifts were simulated by moving the treatment couch on which the phantom was placed and immobilized. While the phantom was shifted from its planning position, a CBCT scan was taken, and 3D/3D matching was performed. The CBCT 3D volumetric image was registered with the planning CT images to reveal the displacement of the real phantom position from its planning position (i.e., the positioning error of the phantom). Then, the phantom position was automatically re-positioned to compensate for the detected shift. Afterward, a second CBCT scan was taken, and 3D/3D matching was performed again to verify the re-positioning accuracy (should be zero). A range of 3D translations are simulated and the corresponding positioning accuracy using CBCT of the OBI system was examined. **Results:** The results for translational shifts indicate that CBCT-based 3D/3D matching is capable of detecting displacements ranging from 1mm to 10mm, and the accuracy is within 1mm. After re-positioning of phantom, the phantom is positioned within 1mm from its planning position. **Conclusion:** The current results indicate that CBCT is capable of detecting positioning errors within 1 mm in three translation directions. More characteristics is to be investigated in the future, such as rotational shifts, image quality (slice thickness), treatment site (other than pelvic), and others. The study is partially supported by a Varian research grant.

SU-FF-J-61

Evaluation of Two CT/MRI Fusion Algorithms Used for Treatment Planning

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Purpose: To evaluate the quality of two CT/MRI image fusion algorithms used for 3D-CRT and IMRT treatment planning **Method and Materials:** Computed tomography-magnetic resonance imaging (CT-MRI) fusion was performed for nine patients with brain/head & neck lesions. Some patients have undergone both three dimensional conformal therapy (3D-CRT) and intensity modulated radiation therapy (IMRT) using two commercially available treatment planning systems which we will refer to as system (1) and system (2), respectively. In order to quantify the fusion results bony landmarks, such as the ramus of the mandible or part of the skull bone, were outlined on the reformatted MRI and the position of the outline in reference to the same bony landmark on the CT image were measured. **Results:** Based on what was acceptable fusion for our clinicians, this preliminary study showed registration accuracy between CT and MRI within 3 mm and 2 mm for system (1) and (2), respectively. On system 2 the quality of the fusion, the bar display, was in the range 62.5% - 100%. We also found that getting full bar (100% - 'perfect match') is possible with reasonable effort if one uses three fiducial marks. Though the bar showed 100% fusion quality the fusion results were not satisfactory. We found better fusion using five or more fiducial points with 62.5 % to 75 % fusion quality. **Conclusion:** Fusion software in both systems provides sufficient CT-MRI fusion accuracy. However, one has to be careful in interpreting the semi-quantitative bar display in system (2) fusion results. We found that instead of going for a perfect matching bar using few fiducial marks one has to use more points, at least five, even if one gets lower percentage match as this is averaged over more landmarks.

SU-FF-J-62

Evolution of Tumor Volume and Motion in Non-Small Cell Lung Cancer During Radiotherapy

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Purpose: To assess changes in tumor volumes and motion trajectories of non-small cell lung cancer patients over the course of radiotherapy. **Materials and Methods:** We acquired repeat CT scans at three time points through the treatment course. Scans were acquired on a Philips large-bore 16-slice scanner using either a respiration-correlated 4D-CT protocol or a breath-hold protocol at moderate-deep inspiration enforced with the Active Breathing Coordinator system. We utilized the Pinnacle treatment planning system to co-register based on vertebral bodies. We contoured the lesions in each data set and measured lesion volumes using model-based segmentation tools. Windowing parameters were kept constant for all scans. Using the contours at each respiratory phase we measured the excursion of the lesion and changes of the excursions from scan to scan. **Results:** Tumor sizes decreased through treatment by 5%, 46% and 48% in three patients analyzed here. The change in the average GTV excursions was (mean ± s.d. over patients): 3.2±4.3 mm (A/P), 0.4±0.6 mm (R/L) and -0.1±3.1 mm (S/I). The 3D vector excursion increased by 2.9±4.2 mm on average. The changes in motion extent are similar to the motion excursion themselves, and there appears to be a strong variability between patients. **Conclusions:** These preliminary data indicate noteworthy trends of tumor size and motion over the course of radiation therapy. The tumor volume decreases and there is indication that the tumor excursion increases. Further analysis is underway and will be presented. Such long term evolution has important implications for the design and delivery of radiotherapy to lung tumors.

SU-FF-J-63

Experience On Cone Beam CT IGRT in Busy Community RT Clinic

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Purpose: X-ray volume imaging (XVI) in image-guided radiation therapy (IGRT), has been under clinical investigation since July 2003 in a few major hospitals. Only since late 2005 the XVI system is available for the general application. We began using the system immediately. The purpose of this presentation is to demonstrate the usefulness of this cone beam XVI system, in a busy single-machine, stand-alone radiation therapy clinic in routine practices; and the results on some typical clinical applications. **Method and Materials:** This clinic has a single accelerator, Elekta Synergy, (Crawley, UK,) with XVI and IView, began clinical application in mid Dec. 2005. In three months, the clinic is currently treating 40 patients daily, with about 30% of the patients receiving IMRT. Within days of training the staff has already adapt the procedure into clinical use. Within a week, the processing time was reduced to three to four minutes per patient. We have done 25 patients; 20 patients are still under treatment. The procedure is applied to soft tissue cases in the abdomen; prostate, anal and rectal, head and neck cases. **Results:** Statistics of the three-dimensional shift are documented for each daily procedure. Over all experience showed

that body procedures, abdomen and pelvis procedures; the range of shift required is from zero to 5 millimeters. For head and neck cases, the shifts are in the range of zero to three millimeters. **Conclusion:** Our experience showed that Elekta Synergy, XVI system is relatively easily to apply to the community clinic setting, without too much complication. We hope to gather more experience on the how IGRT improves upon the non-IGRT IMRT procedures.

SU-FF-J-64

Feasibility of a Feedback-Guided Breath-Hold Technique for Thoracic Radiation Therapy

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Purpose: To determine whether respiratory traces can be used to visually guide breath holds at specified respiratory phases for thoracic radiation therapy; and whether such breath-holds are reducible and effective to reduce treatment margins. **Methods and Materials:** Feedback-guided breath-hold (FGBH) technique was used to provide real-time respiratory traces to patients undergoing radiation therapy of the thorax. The visual signals, depicting the thoracic-motion amplitude and targeted breath-hold levels, e.g. end-expiration (EE) or end-inspiration (EI) were fed back to patients via eye goggles. Patients with distal esophageal cancers near the diaphragm were evaluated for the effectiveness and reproducibility of the FGBH. Simulation CT scans at EE and EI were acquired with repeated FGBHs at multiple sessions. In addition, twice-weekly portal images were acquired with FGBH at EE during treatment courses. On the CT-DRR and portal images, positions of the isocenter and the diaphragm representing the breathing level were measured relative to vertebral axis. The systematic and random errors of the isocenter and diaphragm positions among various image sets were also analyzed. **Results:** The diaphragm movement during free breathing was about 2-3 cm as measured from two patients who completed the clinical protocol so far. For the first patient, the systematic and random errors of the EE diaphragm positions were on the order of 0.6-0.8 cm. The second patient was able to perform the EE breath-hold better with systematic and random errors of the diaphragm positions less than 0.2 cm. The margin needed for the FGBH treatment was 59.1% and 30.7%, respectively, relative to that of the free-breathing treatment for the two patients. **Conclusions:** FGBH technique can be used to effectively reduce the respiratory motion and treatment margin. However, the accuracy of the respiratory monitor, patient training, and compliance are critical steps to ensure the consistency and reproducibility of the breath-hold.

SU-FF-J-65

Feasibility Study of Management of Respiration Induced Target Motion for the Radiotherapy Treatment of Lung Cancer Patients in the Absence of a 4DCT Simulator

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Purpose: Varian's RPM™ system for respiration induced tumor motion management allows acquisition of CT images and gated treatments under free breathing. 4DCT may not be possible because of lack availability of appropriate CT hardware or software. This study evaluated whether a breath hold CT scanning technique can be used as a substitute for a 4DCT scan. **Materials and Methods:** A 4DCT scan is obtained on a 4 slice GE Lightspeed™ scanner with the patient breathing freely and the respiratory period regulated using audiovisual cues from RPM™. Additional helical scans are obtained using an end inhalation or exhalation breath hold modified gating method (MGM). The PTV is drawn on the MGM scan(s) and for each of phase of the 4DCT scan. Comparison of target volume, centroid and extent of target volume is made between the MGM scan and the corresponding phase of the 4DCT scan. A treatment plan is developed using the MGM scan. Dose is recalculated using the 4DCT scan with the beam's isocenter and apertures obtained from the MGM scan. DVH comparison is made. **Results:** 20 patients had both a 4DCT scan and at least one MGM scan. 8 patients exhibited respiration induced target motion of >5 mm during free breathing. Maximum target motion observed was 25 mm. For 14 end inhalation scans, 9 passed, 3 passed marginally, and 2 failed the equivalency tests to the corresponding 4DCT scan. For 18 end exhalation scans, 14 passed, 4 passed marginally, and 0 failed the equivalency tests to the corresponding 4DCT scan.**Conclusion:** All end exhalation breath hold scans are suitable substitutes for the corresponding phase 50 4DCT scan. However only 6/18 patients exhibited sufficient (>5 mm) respiration induced target motion on which to base any conclusions about the suitability of MGM. **Conflict of Interest:** Research supported by Varian Medical Systems.

SU-FF-J-66

Feasibility Study of Mobile Target Tracking by Breathing Synchronized Delivery (BSD)

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Purpose: To investigate the feasibility of mobile target tracking by Breathing Synchronized Delivery (BSD).
Method and Materials: Target breathing motion compensation by real-time tracking of dynamic multi-leaf collimator (dMLC) is under development. We have used an alternative approach to circumvent this problem. Breathing-delivery phase correlation is set in Breathing Synchronized Delivery (BSD) planning. During treatment the feedback is provided to the patients to maintain the correlation. A retrospectively binned 4D-CT was acquired. The full exhalation (50%) phase images were exported to treatment planning system for planning. Smooth tumor trajectory was obtained using deformable registration algorithm and Fourier filtering. With constant dose rate (300MU/min) and breathing period, a motion incorporated BSD plan was obtained by superimposing instantaneous target motion to the leaf position at corresponding phase. BSD plan was delivered using the dynamic dose mode with a Varian's dMLC. For dosimetric verification, a computer controlled mobile phantom was used to simulate the actual superior-inferior target motion obtained from 4D image registration. Dose was measured at the isocenter of the phantom in the coronal plane using EDR-2 film. Three films were exposed, first for static phantom and conventional plan, second for the moving phantom and conventional plan and third moving phantom with motion compensated BSD plan. **Results:** The dose distributions in superior-inferior direction were very similar if BSD planning is used on mobile phantom. Underdose and overdose of the order of 20% were observed at the superior-inferior direction if motion is not compensated. **Conclusion:** Phantom dosimetry results show that BSD planning and delivery method can effectively compensate target motion. For the patients who may maintain reproducible breathing pattern with video or audio instructions, BSD method is a simple alternative to real-time tracking.

SU-FF-J-67

Fiducial-Based Translation Alignment Accuracy of An AC Electromagnetic Tracking System and On-Board Kilovoltage Imaging Localization System

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Purpose: On-board kilovoltage imaging is being used for accurate fiducial-based alignment of tumors. However, these systems deliver additional dose to the patient and do not allow interactive repositioning with the therapist in the room. The purpose of this study is to measure and compare static localization accuracy of a commercial on-board kilovoltage imaging system and a novel AC electromagnetic tracking system. **Materials and Methods:** A kilovoltage imaging system (Trilogy™ System, Varian, Palo Alto, CA) and an electromagnetic tracking system (Calypso® 4D Localization System, Calypso Medical, Seattle, WA) which provides a continuous measurement of the implanted transponder positions, were compared for localization accuracy. A phantom containing three radiofrequency transponders was moved, using an in-house developed 4D phantom (with a 0.4 mm position accuracy), in steps from 0.4 cm to 5 cm in the lateral, longitudinal, and vertical directions. The transponder positions were measured using the commercial matching software using antero-posterior and lateral images and comparing against DRRs. These results were compared against the Calypso System measurements. **Results:** The localization accuracy, defined as the average difference of the measured positions (by the localization systems) to the actual positions (as determined by 4D- phantom positioning system) was found to be 0.0 ± 0.00 cm, 0.1 ± 0.1 cm and 0.1 ± 0.0 cm in three directions for KV system

and 0.0 ± 0.0 cm for the Calypso system. Results showed that both systems provided excellent positioning accuracy.

SU-FF-J-68

First Clinical Results of An Adaptive Off-Line Radiation Scheme Using Cone-Beam CT Scans for Treatment of Prostate Cancer

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Purpose: We developed an adaptive scheme for prostate cancer radiotherapy based on kV cone-beam-CT (CBCT) images that are obtained on the machine during the first six treatment days. The aim of this scheme is to improve knowledge of the average prostate position and average rectum shape and safely reduce the PTV margin. **Method and Materials:** CBCT-scans, acquired our on Elekta Synergy systems, were first matched on the planning CT scan using the pelvic bones. Automatic grey-value matching was then used to match the prostates of the CBCT-scans to the prostate of the planning CT scan. The mean of the obtained translations and rotations was used to move the prostate of the planning CT scan to its average position. Subsequently, the rectal wall was delineated in the CBCT-scans, and coordinates of corresponding points of the 7 rectums were averaged to obtain the average rectal wall. Based on average prostate and rectum a new IMRT treatment plan was made with a reduced PTV margin of 7 mm. Weekly CBCT-scans were made to verify that the new PTV encompasses the prostate. **Results:** So far, 16 patients were successfully treated with our adaptive treatment scheme. For 85% of the CBCT-scans a successful grey-value match was obtained, the other scans were discarded. For 88 out of 89 verification scans the prostate was inside the PTV. The mean dose received by the rectum reduced on average by 7.6%, and the equivalent uniform dose (a=12) by 1.5%. **Conclusion:** This is the first routine clinical application of soft tissue image guidance for the prostate using kV CBCT. Contrary to adaptive schemes that use implanted markers, our method is non-invasive and improves localization of both prostate and rectum. **Conflict of Interest:** Elekta, Inc financially supported part of this study.

SU-FF-J-70

Geometric Accuracy of a Real Time Target Tracking System with Dynamic MLC

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Purpose: Dynamically compensating for target motion during radiotherapy will increase treatment accuracy. A laboratory system for real time target tracking with a dynamic MLC has been developed. In this study, the geometric accuracy limits of this DMLC target tracking system were evaluated. **Method and Materials:** A motion simulator was programmed to follow patient-derived tumor motion paths, parallel to the leaf motion direction. A target attached to the simulator was optically tracked, and the leaf positions adjusted to continually align the DMLC beam aperture to the target. Analysis of the tracking accuracy was based on video images of the target and beam alignment. The system response-time was determined and the tracking error measured. Response-time-corrected tracking accuracy was also calculated to investigate the accuracy limits of an improved system. **Results:** The response-time of the system is 160±2ms. Because of this response-time, the tracking error is largest when the target velocity is highest. The geometric precision for tracking patient motion is 0.6-1.1mm (1σ) for the three patient datasets tested. The systematic tracking error is very small in all cases (<0.1mm). **Conclusion:** A DMLC target tracking system has been developed that can account for detected motion parallel to the leaf direction. The overall geometric accuracy of this system is very promising, with negligible systematic tracking errors and ~1mm random tracking errors. Reducing the response-time will further increase the overall system accuracy. **Conflict of Interest:** Two authors are principal investigators on sponsored research agreements between Varian Medical Systems and their respective institutions. One author is an employee of Varian Medical Systems.

SU-FF-J-71

Gross Tumor Volume Measurement of Simulated Lung Nodules Using PET Imaging

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Objective: The aim of this study is to determine the PET image threshold that will generate the most accurate measurement of gross tumor volume (GTV) of lung nodules. **Methods:** A NEMA IEC phantom containing six spheres of different sizes (10, 13, 17, 22, 28, and 37 mm diameter) was scanned on a DISCOVERY ST PET/CT scanner. The phantom was scanned three times. In each case, the sphere to back ground ratio was varied (3.4:1, 7.4:1, 13.5:1) while keeping the activity concentration in all spheres constant. To simulate tumor motion, the phantom was positioned on a unidirectional translating platform. A sinusoidal waveform (5 sec cycle, 2cm peak to peak) was used to drive the platform during the PET data acquisition. The platform motion was tracked using an RPM device which sent a trigger signal to the PET scanner at a specific phase of every repeating cycle of the waveform. PET data was acquired in 2D for 30 minutes using LIST mode (10 bins per cycle). PET images were then reconstructed using OSEM. An in-house software program was then used to find the percent threshold that best estimated the true known sphere volume. The program was written to perform the analysis at an increment of 1% in threshold. **Results:** Spheres that have minimum partial volume effects (>17 mm) had an average threshold of 32% ±2.8 at different contrast ratios. The smaller spheres had a larger threshold value and a larger standard deviation. The results also showed that the threshold for the small spheres increased with decreasing contrast ratio. For the 13 mm sphere the threshold changed from 27% to 55% when using a contrast of 13.5:1 to 3.4:1. **Conclusion:** A threshold of 32% gave the most accurate GTV. The effects of scan duration on this threshold will also be presented.

SU-FF-J-72

Growth and Initial Area Under Curve Correlation Data From DCE-MRI For Treatment Planning and Monitoring in Orthotopic Tumor Models

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Purpose: Human bladder carcinoma cells are grown in murine bladders to study antitumor effects of new-targeted therapies. Lack of data on their neovascularity in mice, makes it difficult to evaluate new therapies like anti-angiogenesis or potential of combinatorial treatments like radiation and hyperthermia. The purpose of this study is to understand the changes in neovascularity with tumor growth in relevant organ environment, with dynamic contrast enhanced magnetic resonance.
Method and Materials: Eleven athymic nude mice underwent orthotopic injection of 10^6 253-J B-V cells. MR imaging was performed on a 4.7 T small animal MR scanner (Bruker Biospin). Axial T1 weighted spin-echo and T2 weighted fast spin-echo acquisitions were performed for volumetric measurements. For dynamic studies, an axial 3D fast RF-spoiled gradient-echo acquisition (TR:40ms,TE:1.4ms,slice thickness:1mm) with gadolinium-DTPA (Magnevist, Schering) was used. The time points for imaging were day 15, day 21 and day 30 after inoculation. **Results:** The MR volume measurements were made from the fused T1 and T2 images, which were shown to better delineate tumor margins in previous experiments. The initial area under the curve was plotted at 90 seconds, 120 seconds and 200 seconds. An inverse relationship was noted between larger tumor sizes and their $IAUC^{90}$ (correlation=-0.866 ($p<0.05$). There is no correlation between the slow growing tumors and the $IAUC^{90}$ ($p=0.708$). No significant difference was noted between $IAUC^{90,120,200}$ of the whole tumor and tumor rim ($p<.05$). **Conclusion:** The inverse relationship between the IAUC and tumor growths maybe indicative of developing necrotic core. The IAUC and tumor growth data correlation could be a predictive tool for radiation response. It could also assist in planning time points for anti-angiogenic therapy. In future, we plan to use a higher molecular weight gadolinium agent, and stain the tissue for mean vessel density.

SU-FF-J-73

Helical Tomotherapy Sinogram Deformation for Daily Adaptive Therapy

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Purpose: To develop an algorithm for modifying a helical tomotherapy treatment delivery sequence based on a measured deformation and to test the algorithm by displacing artificially created test cases, and clinical test cases. **Method and Materials:** A geometric test case was created consisting of an equilateral triangle with a 5.2-cm base located inside a circle with a 3.14-cm radius. The circle/triangle extended uniformly superior/inferior for 3-cm, and was centered at the machine isocenter. An inverse plan was created with the triangle irradiated to 2 cGy, and the circle irradiated to 1.5 cGy, yielding a 64 x 701 delivery sinogram. A clinical prostate treatment delivery was also used, where the Planning Target Volume (*PTV*) consisted of the prostate and seminal vesicles. The PTV was treated to 2 cGy per fraction, resulting in a 64 x 660 delivery sinogram. A program was developed to shift the MLC positions in each sinogram by a measured displacement of the target. A dose profile (*measured with an ionization chamber*) was incorporated into the algorithm to correct for off-axis factors. The dose distributions for displacement test cases were offset by known amounts, and then measured using Kodak EDR2 radiographic film and Computed Radiography (*CR*) plates placed axially on a tomotherapy treatment couch. The distance of the dose shifts from isocenter, and the absolute doses were measured and compared between the original film, and the film with the vertical shift with and without off-axis correction. **Results:** The delivery sinograms for the test cases were offset by 2.5 cm in only the vertical direction, 2.5 cm in only the horizontal direction, and 2.5 cm diagonally using the deformation algorithm. The measured distances were within 5 mm of the desired position. **Conclusions:** Presently, the deformation algorithm can correct for displacements up to 5 cm on a treatment slice.

SU-FF-J-74

High Accuracy of Volumetric Image Registration of CT, MR and PET Images

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Purpose: To test the accuracy of the 3D volumetric image registration technique, the registration has been evaluated against "co-registered" CT phantom images, MR/MR intramodality images and PET/CT images. **Method and Materials:** The 3D volumetric image registration is voxel-based, using the homogeneous color distribution in the volumetric views of the skin voxel landmarks as the registration criterion and guidance for alignment. The software is built for up-to-4 concurrent imaging modality registration with real-time volumetric manipulation and display (supported by a volume rendering board). Sixteen CT head phantom images are acquired with known spatial shifts, as well as fourteen patient cranial MR/MR (T1/T2/FLAIR) images from the same MR scanner and twenty-five patient cranial PET/CT images from a hybrid scanner. **Results:** A sub-voxel detection limit (0.1 degree/voxel) is achieved for CT/CT phantom image registration as the alignment is indicated by the color homogeneity of the aligned skin voxels, which represents a new dimension for monitoring the image registration. For the MR/MR image registration, it is found that 71% of the "co-registered" images acquired from the same scanner within 5 minutes of each other exhibit a misalignment, caused by voluntary patient movement. The "distance" deviations ($\sum(X_i^2)^{1/2}$) between the co-registered and voxel-registered images are 0.2°±0.4° and 0.5±0.5 voxels. For the PET/CT image registration, 88% images have detectable misalignment due to higher probability of patient movement during longer scan time (<10 minutes) and the deviations are determined to be 0.4°±0.5° and 0.9±0.5 voxels. These movement-induced misalignments can be corrected using the 3D volumetric image registration technique. **Conclusion:** The 3D volumetric image registration technique has sub-degree/sub-voxel accuracy in CT, MR and PET image registration. It can successfully detect misalignments in the co-registered images visually and should be applied to correct the image misalignment caused by voluntary patient movement.

SU-FF-J-75

High Performance Dual KV & MV Imaging with One Detector

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Purpose: Recent developments in Adaptive Radiation Therapy (ART) leverage MV and kV X-ray imaging to acquire patient images in treatment position. We have developed a kV X-ray imaging system, in line with the MV treatment beam, which enables us to acquire: (i) 2D kV X-ray images (single acquisitions and fluoroscopy) simultaneously with the MV treatment, (ii) 3D tomographic kV X-ray images, and (iii) MV beam pattern and profile (for entrance dosimetry). Our imaging system utilizes a detector with wide dynamic range allowing us to achieve these technically challenging objectives. Methods and Materials: In the in-line imaging system, the kV source is opposite to the linear accelerator target with its focal point 100cm from the isocenter. During kV imaging, the kV detector is deployed close to the exit window of the MV beam, which adds to the intensity of the MV beam seen by the detector. Providing all the possible modes of imaging requires a large dynamic range for the flat panel imager. Two multiple gain detectors from Perkin Elmer Optoelectronics were evaluated (XRD1640AN & XRD1621AN), their acquisition and interface parameters were defined. **Results:** kV CBCT imaging allows for 1% contrast in 4mm object to be visible with a dose of 3.4cGy (120kV) using 1mm slice thickness. Cross sectional images of a bar resolution phantom with a 512^3 reconstruction allow for 0.9 lp/mm bars to be resolvable. Both detectors were evaluated for saturation at multiple MV energies. **Conclusion:** We have developed an imaging system that provides a challenging combination of high quality 2D KV imaging simultaneous with the MV treatment beam, 3D kV CBCT volumetric images, and the acquisition of the MV beam shape and profile (for entrance dosimetry). **Conflict of Interest:** Sponsored by Siemens

SU-FF-J-76

How to Account for Patient-Specific Tumor Motion in Target Definition for Lung Cancer Treatment Planning: Dosimetric Comparison of a Multi-Phase CT Simulation Approach and MRI Cine Study

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Purpose: In order to account for tumor motion, a multi-phase CT scanning and MRI cine imaging were used to assist planning target volume (PTV) definition in treatment planning. In this work, we compared tumor coverage in the subsequent treatment delivery using these two approaches. **Materials & Methods:** Consented patients underwent CT simulation consisting 2 short scans taken at maximum inspiration and expiration breath holding conditions, in addition to a normal free-breathing scan. These same patients went through MRI cine scanning. For treatment planning and delivery, we constructed a PTV from a combination of the targets delineated on all 3 CT scans after image registration by applying 3 mm margin (termed PTV_3CT). For this study, another PTV expansion was generated from the gross tumor volume (GTV) on the free breathing scan by margins that were determined by MRI cine (termed as PTV_MRI). Treatment planning using the same beam configurations and weights was performed on the PTV_MRI. Since a localization CT scan was obtained for each patient using a CT-on-rails system prior to each treatment, we are able to obtain the actual GTV in treatment position (GTV_tx) and compare their coverage for the plans designed for either the PTV_3CT or PTV_MRI. **Results:** For 5 patients and 20 GTV_tx studied, they were all within the PTV_MRI geometrically and have full dose coverage in terms of D_{95}. However, for plans designed for PTV_3CT, 9 out of 20 of the GTV_tx were found, at a varying degree, to be partially out of the PTV_3CT and the coverage varies from 95.9% to 100% of the planned values. Although the difference in coverage is small, it is statistically significant, as the p-value for the t-test is 0.006. **Conclusions:** The MRI-cine appears to be a better study of motion than the multiphase CT approach in this study.

SU-FF-J-77

Image Quality Assessment for An Investigational Megavoltage Cone-Beam CT Device

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Purpose: Megavoltage Cone-Beam CT (MVCBCT) is an essential image guided radiation therapy (IGRT) device to acquire patient's daily treatment CT for accurate localization of treatment targets. The objective of this research was to assess its image qualities. **Method and Materials:** The image quality of MVCBCT was assessed by four indicators: noise, contrast, spatial resolution, and CT intensity stability. A CT electron density phantom and a Siemens calibration phantom were used. The images were acquired under various MU settings. The Siemens Syngo image processing software was used to sample and analysis the data. **Results:** The noise factor was used and found that the more MU to acquire the images produced less noise. 6 MU is the cut-off value for noise factor of less than 5%. For contrast of the outer ring of the CT phantom, the electron density range of <0.952 and >0.976 were visible on all MUs. For the inner ring, we only see <0.952 and >1.052 on MU <9 and >1.043 for MU > 15. For the CT intensity stability, if the CT number differences has to be <50 to qualify as "stable", then 6 MU is the border line. For spatial resolution, MTF was used to evaluate Siemens phantom images. The lp/mm at MTF = 0.5 was 0.07, a little less than the criteria of 0.08 and for MTF = 0.1, we had 0.28, which is >criteria of 0.25. **Conclusion:** The images from MVCBCT device were assessed for quality indicators; we conclude that the MU of 6 or above would have satisfactory results. For the future application of dose calculation on the MVCBCT images, the CT intensity stability is important, and we found that for 6 MU and above would have stable CT numbers.

SU-FF-J-78

Implanted Marker Movements During Prostate IMRT

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Purpose: To quantify positional variations of implanted markers for prostate localization using the ExacTrac system. **Method and Materials:** Eleven patients were identified as having undergone IMRT boost for prostate cancer. The ExacTrac system was used to obtain implanted marker positions in the patient by means of two stereoscopic X-ray tubes and DRRs from CT simulation. Marker positions were recorded by the ExacTrac software and subsequently read using the PTDreader software. Implanted marker positions were analyzed for variations in individual maker coordinate displacement, inter-seed distances and area transcribed by the three markers. Comparisons of patient data was done for the initial boost phase (1980 cGy/11 fractions) and final boost phase (1080 cGy/6 fractions). **Results:** Implanted markers had maximum deviations of 3.3 mm (LAT) 6.4 mm (AP) and 3.4 mm (SI). In cases where the maximum deviation was observed for one coordinate the other coordinates were also approaching their maximums. No correlation between individual marker positions was observed. Inter-seed distances were found to vary by +/- 2 mm over the treatment period. The area of a triangle contained by the three markers was shown to vary daily over the treatment period. In the 6 patients who were observed over both boost phases a trend was observed that indicated a progressive decrease in the area for the 4 patients not on hormone therapy and stable area size for the two on hormone therapy. Of the 11 patients followed over the final boost phase 8 were found to demonstrate a similar decrease but no correlation with hormone status was observed. **Conclusions:** Implanted markers in the prostate demonstrate daily variations in their positions. The observed variations exceeded the precision of the ExacTrac system. Further work is needed to address the movement of implanted markers in the prostate in positioning algorithms and correlation with prostate volume.

SU-FF-J-79

Implementation of Four Different Image-Guided Radiotherapy (IGRT) Systems in a Radiotherapy Department

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Purposes: to implement and compare four newly developed image-guided radiotherapy systems (Varian's Cone-Beam CT, BrainLAB ExacTrac, Restitu Ultrasound (U/S)-Sim and Guide, and in-house stereovision) in one department. **Methods and Materials:** The cone-beam CT (CBCT) and the ultrasound (US) systems provide volumetric images of the target at daily setup. The ExacTrac system acquires the biplanar radiographs at patient setup. Both the US and ExacTrac systems are integrated with infrared-tracking systems for patient-couch positioning. The in-house stereovision system captures 3D surface images of the patient at the instants of daily patient setup and during individual beam irradiation. All of four IGRT systems have used treatment planning volumetric imaging information for target position verification and adjustment. Electronic portal images are routinely used for patient position verification. External markers and possible internal markers such as seeds or small cysts or calcifications can be localized and used for additional verification. **Results:** Emerging data from several institutional IRB-approved clinical trials demonstrate that the target reposition error and dose delivery uncertainties can be significantly reduced by using such image-guided systems, each of which may be most useful in specific clinical situations. **Conclusions:** Our customized stereovision system, which, like US, involves no radiation exposure, is extremely efficient (<2 minutes) and accurate (<2 millimeters) for superficial sites, such as breast cancer. The ExacTrac system appears ideal for lesions associated with bony structures, such as spine and skull. The US and CBCT may be most useful for deformable internal structures, such as prostate cancer. Special methods for dealing with imaging artifacts, such as ring patterns in CBCT, shadow casts and multiple reflections in stereovision and US, and patient motion in ExacTrac and stereovision will be presented.

SU-FF-J-80

Implementation of On-Board Imager for Daily Image-Guided Radiation Therapy in a Multi Vendor Environment

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Purpose: To report our initial experience of using Varian On-Board Imager (OBI) image-guided radiation therapy (IGRT), on a prostate patient with implanted fiducials. Varian's OBI-IGRT system enables clinicians to obtain high-quality daily kV images of the patient in treatment position. An attempt has been made to implement and evaluate various possible workflow issues, when using the Varian OBI system in a multi vendor environment. **Method and Materials:** Daily shifts based on OBI images were made on an implanted fiducial prostate patient who underwent treatment on a Varian Trilogy Clinac. Using Varian's OBI 2D/2D matching software, orthogonal kV images were compared to Pinnacle[3] (Philips) DRR's generated from the planning CT, to determine and correct for any daily target shifts. The kV images were transferred to our record and verification system IMPAC MultiAccess (Elekta), for physician review. The shifts predicted by the Varian software using manual matching, was compared daily, with the shifts predicted by the Acculoc software (Medtec), based on three implanted fiducials. In addition, cone beam CT (CBCT) scans were acquired once a week, to predict shifts using our in-house developed 3D/3D- matching software. **Results:** Daily shifts predicted by the Varian OBI 2D/2D software, matched daily shifts predicted by the Acculoc fiducial alignment software to within 1 mm during the entire treatment course. The weekly CBCT scans also confirmed that these shifts were within 1 mm on the same treatment days. Various software issues were discovered and workarounds were proposed using in-house solutions. For example, the electronic graticule could not be transferred to ACCESS from the OBI software, etc. **Conclusions:** In-house validations and implementations were needed to make all pieces of equipment work together correctly. Once the workflow was established, we demonstrated that OBI based IGRT solutions was consistent and clinically acceptable across different vendor's solutions.

SU-FF-J-81

Importance of Daily Portal Imaging for Head and Neck IMRT Treatments

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Purpose: To investigate the set up variation for head and neck IMRT patients based on daily portal imaging. **Method and Materials:** Reproducible patient setup is critical to accurate delivery of head and neck IMRT. At our institution, these patients are immobilized using a head-neck-shoulder thermoplastic immobilization system (S-Type, Medtec) and a customized headrest. Orthogonal digital portal images are taken daily to check patient positioning and are compared with plan DRRs. Isocenter misalignments are corrected by the therapists using a couch shift, with a 3mm action level. Therapists also carefully examine patient positioning in the mask, especially shoulder position, and re-position the patient in the mask if considered necessary. Isocenter shifts and frequency of patient repositioning were investigated by review of record-and-verify records for 15 patients. The magnitude of the shoulder respositioning was evaluated for 10 patients by comparing portal images and plan DRRs for a point 8cm inferior of isocenter, which is typically located at C2. **Results:** Isocenter discrepancies of 3mm or smaller were recorded for a median of 92.5% of fractions (range: 71.4 – 100%). Isocenter shifts larger than 5mm were only recorded twice (2 patients, 1 fraction each; 0.38% of all fractions). On the basis of pre-treatment daily imaging, patients were repositioned in the immobilization mask before treatment for a median of 14% of fractions (range: 3-34%). Fifty nine percent of these repositioning were for a shoulder shift of less than 5mm. Thirty percent, however, were for shoulder shifts of 1cm or larger. **Conclusion:** With our current immobilization, daily isocenter positioning accuracy is excellent, while correct shoulder position is more variable. Frequent imaging of head and neck IMRT patients is essential to accurate delivery of therapy, with shoulder position an important factor.

SU-FF-J-82

Improving Soft Tissue Contrast in 4D CT Images of Liver Cancer Patients Using Deformable Image Registration Method

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Purpose: To investigate image quality improvement in 4DCT images of liver cancer patients by using deformable image registration. The low soft-tissue contrast in liver CT images is always a challenge for accurate target delineation. **Method and Materials:** Ten patients with liver cancers were selected in this study. These patients received 4DCT scans for radiotherapy treatment planning using 120kVp and 150mA on a GE PET/CT system. The 4DCT images were retrospectively sorted and binned into 10 equispaced phases. The end-expiration phase was chosen to be a reference phase, and the images from the other 9 phases were co-registered to the reference phase using an intensity-based, automatic deformable image registration algorithm. Then the 10 matched 4DCT images were averaged to give a single, high quality reference-phase CT image for tumor target delineation. The image quality enhancement was quantified relative to the original CT by calculating the signal-to-noise ratio (SNR) inside the liver region. The incremental improvement in image quality was also studied by combining fewer 4DCT data sets. **Results:** The image contrast in the soft tissue region is noticeably improved. SNRs inside the liver increased for all patients by a factor of at least 2.3 (average at 3.0). The improvement in image quality is not linearly proportional to the number of images averaged. Averaging 6 CTs can achieve 85% of the SNR enhancement obtained by averaging all 10 CTs of different phases. **Conclusion:** We developed an effective method to improve soft tissue contrast in the liver by co-registering and combining multiple CTs within the 4DCT data set using a deformable image registration method. The resultant, high-quality, single-phase CT could be used for better delineation of tumor target volume and critical avoidance structures. The deformable image registration method can also map these contoured structures back to each individual phases for motion-compensated 4DCT planning.

SU-FF-J-83

Inaccuracy of Fixed Threshold Segmentation for PET

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Purpose: Several automatic segmentation methods have been developed to aid physicians in drawing tumor contours from PET images. Our goal is to compare the consistency of current methods for delineating in vivo tumors and uniform objects in phantom. **Method and Materials:** We compare three published methods, each based on a single threshold value per scan, for segmenting objects in experimental or Monte Carlo simulated PET scans of cylinders and spheres with uniform activity concentration in a phantom, and for segmenting tumor volumes in the torso from 20 patient PET scans. **Results:** For uniform activity objects in phantom, segmented volumes generated by the 3 methods differ from true values by more than a factor of 2. The segmented volumes are within a factor of 3 and 4 of the true volume when the objects are larger than twice the PET resolution. Between the methods, the segmented volumes differ by up to 78% and 93% for objects in zero and non-zero background respectively. These differences are close to the volume change caused by adding a single voxel layer to the surface of the object. The discrepancies between the different segmentation methods are even larger for segmenting in vivo tumors where volume differences larger than a factor of 10 were observed, far larger than the single voxel enlargement effect. **Conclusion:** Threshold value based segmentation methods can be used only as a rough guide for tumor delineation and then only after adapting to each clinics PET scanner and procedures. Among the probable sources of inaccuracy are various patient dependent factors including tracer uptake non-uniformity. This suggests that effort in analyzing PET images should be shifted towards providing accurate quantitative information to the physician to improve confidence in target delineation amidst the various phenomena affecting the PET image. Supported in part from NCI Grant P01-CA59017.

SU-FF-J-84

Integration Of 3D Stereovision System In Image-Guided Radiotherapy: A DICOM-Based Method

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Purpose: To seamlessly integrate a 3D stereovision system (or 3D camera in short) with complex planning and treatment systems and implement a 3D image-guided patient positioning for radiotherapy of breast cancer. **Method and Materials:** A high speed commercially available 3D camera is installed on the ceiling of treatment room to capture real-time 3D surface images of patient. After transformed from camera coordinate system to treatment machine coordinate system, the real-time 3D surface image is matched with a 3D reference image which is defined in planning systems. A stack of external contours with position information from DICOM RP and RS files are re-sampled to generate a 3D reference image. Regions of interest (ROIs) of both images are defined by the PTV parameters from DICOM RP files. An Iterative Closest Points (ICP) algorithm is adopted to conduct the registration of ROIs. The parameters of patient positioning derived from the registration can be used to adjust the patient position. **Results:** Outliers and noise of captured 3D surface images are automatically and effectively removed when applying PTV parameters to define ROIs. Phantom test and An institutional IRB approved clinical trial indicates a typical case of image-guided RT, including loading reference images, capturing real-time images, and image matching can be done in less than 1 min. By double checking with online EPID, a millimeter positioning accurate can be achieved without considering deformation of images. **Conclusions:** This work shows the clinical potential for utilizing a 3D camera in image-guided RT. The integration of 3D camera in image-guided RT based on DICOM standard provides faster and more precise patient positioning than other image-guided RT. How to deal with the deformation of ROIs will be our research direction in future.

SU-FF-J-85

Inter-Observer Variation In The Planning Of Head/Neck Radiotherapy

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Purpose: Understanding inter-observer variation is not only important for evaluating deformable image registration (DIR) which can be used to automatically transform the manual contours of a treatment plan into daily contours facilitating offline or online adaptive radiotherapy, but also helps physicians set reasonable margins on the regions of interest (ROI) when they make treatment plans. The purpose of this study is to determine the observer variation for Head/Neck patients using the implemented radial-difference approach and the common-area method to study the observer-drawn contour pairs. **Method and Materials:** Two sets of images for each of seven head and neck patients were taken several weeks apart, and the original image sets were used for treatment plans. For each image set, the ROIs: Primary GTV, Nodal GTV, Cord, left Parotid, and right Parotid were contoured by three experienced physicians. The difference of two contours drawn by different physicians was measured using: (1) the radial difference of the paired contours where the center-mass of a contour is used as the origin of the polar coordinate system, and (2) the ratio of the common area of two contours over the total area of those contours, $R = 2[(C1 \cap C2)/(C1 \cup C2)]$. Results for all the ROI are plotted in histograms to quantify the observer variation.

Results: The radial differences for primary GTV, nodal GTV, cord, left parotid, and right parotid are 2.7 ± 2.0 mm, 2.4 ± 1.9 mm, 1.8 ± 0.8 mm, 2.6 ± 2.1 mm, and 2.5 ± 1.9 mm, respectively, and the values of R are 0.75 ± 0.14, 0.82 ± 0.11, 0.82 ± 0.07, 0.80 ± 0.10, and 0.80 ± 0.12, respectively. **Conclusion:** The inter-observer variations in the planning of Head/Neck patients are about 3 mm for Cord and 5 mm for the others. These values place an upper limit on the accuracy of DIR algorithm.

SU-FF-J-86

Intra- and Inter-Breath-Hold Position Variations for OBI Guided Amplitude Gating Treatment with Breath Hold

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Purpose: We have applied OBI guidance together with a respiratory gating system to effectively control patient positioning for amplitude gating treatment with breath hold. The deep inspiration breath-hold treatment has been proven effective in reducing the heart dose for left-breast treatment. Breath-hold technique is also useful for other sites where respiratory motion exists. In this study, we quantified the degree of intra-fraction motion detected via continuous monitoring of patient position throughout treatment delivered during a single breath hold or multiple breath holds. **Method and Materials:** A real-time position management (RPM) system (Varian, CA) was used to monitor radiation treatment for patients with tumors located in the thoracic through upper-abdominal regions and the left breast. Simulation CT scans were acquired during breath holds when the breathing level was between the upper and lower thresholds that were pre-set in the RPM system. OBI kV radiographs and CBCT images were used to verify the patient position and breath-hold level during the treatment sessions. To assure accurate positioning, the OBI/CBCT images were acquired only when the breathing level was within the same thresholds as those used for the simulation CT. Cine mode portal vision images were acquired every second during treatment. The intra- and inter-breath-hold position variations were analyzed based on the cine mode portal vision and kV radiographic images. **Results:** The intra-/inter- breath-hold position variations were analyzed for a total of ninety two fractions in six patients undergoing OBI guided breath-hold treatments. The breath hold length ranged from 10 to 50 seconds. The intra-breath-hold position variation was within 2 mm. The inter-breath-hold position variation, within the same fraction, was within 4 mm. **Conclusion:** With proper OBI guidance and respiratory gating, the breath-hold technique can effectively control the target position for treatment of cancer sites where respiratory motion exists.

SU-FF-J-88

Intra-Fraction Prostate Motion and Margin Calculations for Prostate Radiotherapy Using Electronic Portal Imaging, Implanted Fiducials and Four Localization Methods

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Purpose: This study presents the margins required for prostate EBRT if daily localization is based on skin marks, daily gold seed localization with a fixed threshold for correction, daily gold seed localization with no threshold, and daily bony anatomy alignment. The extent of intra-fraction motion of the prostate is also presented. Method & Materials: Fiducial markers were placed in the prostate and their position was determined based on CT. Skin marks established initial localization (84 patients). The second localization method (40 patients), used orthogonal pretreatment electronic portal images to visually match the markers. If the 3D offset exceeded 5mm, the patient was shifted. The no threshold result was taken as the subset of the patient fractions where shifts occurred in method 2 (40 patients, average of 21 fractions). The final localization technique was bony anatomy match (67 patients). Through-treatment EPIs were taken to document the prostate position during treatment; they were used to determine the margin for the fiducial localization and intra-fractional analysis. Intra-fractional analysis on 40 patients was accomplished by comparing the position of a particular seed between opposing treatment fields. Results: Margins for tattoo localization: Left-Right 5.1mm, Inf-Sup 5.8mm and Ant-Post 8.4mm. Margins for the EPID with fiducials: Left-Right 3.4mm (2.9mm with no threshold), Inf-Sup 3.3mm (2.7mm with no threshold) and Ant-Post 3.3mm (2.8mm with no threshold). Bony anatomy margins: Left-Right 2.6mm, Inf-Sup 7.3mm and Ant-Post 8.9mm. Margins intra-fraction motion: Left-Right 2.1mm, Inf-Sup 2.8mm and Ant-Post 3.0mm. Conclusion: EPID localization allows a drastic (~60%) margin reduction when compared to tattoo localization. Except for the Left-Right, localizing on the bony anatomy leads to worse margins then tattoo setup. A significant intra-fractional prostate motion exists which is a limiting factor on margin reduction. **Conflict of Interest:** Partial funding provided by Varian Medical Systems.

SU-FF-J-89

Intratumoral Pattern of FDG Uptake in Human Xenograft Models

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Purpose: To investigate the spatial association between intratumoral uptake of ^{18}F-fluorodeoxyglucose (^{18}F-FDG) and the following characteristics of the tumor microenvironment: hypoxia, cellular proliferation, and blood flow; and to evaluate the potential impact of this association on the use of ^{18}F-FDG images in radiation oncology treatment planning for target volume delineation. **Method and Materials:** Six nude rats were inoculated with the following human tumor cells: HT-29 (colon adenocarcinoma), DU-145 (prostate carcinoma), and A549 (NSCLC). When the tumors reached 20-25mm in diameter, the animals were injected with ^{18}F-FDG, pimonidazole, and bromodeoxyuridine. 1hr post injection animals were imaged on animal PET scanner. Upon completion of imaging, animals were injected with Hoechst33342 and sacrificed with CO_2 5-10min later. Tumors were immediately dissected, frozen and cut into 8μm thick sections. One section from each tumor was placed onto a phosphor plate for autoradiography. The images of the fluorescence produced by Hoechst33342 and by fluorescent antibodies raised against pimonidazole and bromodeoxyuridine were acquired from the adjacent sections and co-registered. The statistical analysis of association between PET tracer uptake and microenvironmental markers was then performed on a pixel-by-pixel basis. **Results:** In all the tumor models studied, we observed positive pixel-by-pixel correlation between FDG uptake and pimonidazole staining intensity (correlation coefficients ranged from 0.46 to 0.87, $p<0.001$). At the same time, correlation with bromodeoxyuridine was always negative (ranged from -0.50 to -0.78, $p<0.001$). **Conclusions:** This study further confirms association between foci of increased intratumoral FDG uptake and regions of hypoxia. In addition, it demonstrates reduced FDG uptake in actively growing parts of the tumor. Therefore, the use of FDG uptake iso-contours to delineate lesions and, especially, to reduce target volume with respect to CT-defined volume should be approached very carefully, since it might potentially result in exclusion of areas of active tumor growth from the target volume.

SU-FF-J-90

Investigating Factors Affecting Weight Selection for Safe Delivery of Four Dimensional Weighted Radiotherapy (4D-WRT)

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Purpose: We have developed a 4D weighted radiotherapy (4D-WRT) method based on 4D-CT imaging to reduce respiratory motion margins. Here we discuss the issues related to weighting factor selection for this method to incorporate both patient breathing variability and machine performance limitations. **Method and Materials:** The Varian Real Time Position Management System (RPM) was used to measure patient respiratory motion. Free breathing was assessed based on extent of motion, breathing period, and drift of the mean breathing amplitude. Motion was also evaluated based on average marker trajectory as a function of phase for the entire breathing session. Measurements of machine limitations were conducted using a moving phantom to emulate tumor motion. The MLC motion was synchronized with the phantom motion to simulate 4D-WRT. By examining log files and film dosimetry we assess MLC motion accuracy, dose rate fluctuations, synchronization errors, and tolerance selection. **Results:** The analysis of the average marker trajectory shows that the end-inhale position is more variable than the end-exhale position, and patients spend more time at end-exhale. The average extent of motion, period, and drift for these patients was 1.01cm (0.14-1.15cm), 3.80sec (2.30-7.42sec), and 0.50cm (0.14-1.15cm), respectively. There was a correlation between the standard deviation of the period and that of the extent of motion. In the log file it was found that there is a phase delay between the actual and planned MLC position of 50msec, the period of motion was greater by 1% and the amplitude was greater by 0.05cm. It is estimated that a total phase difference of about 0.2sec exists due to delays in the communication, MLC motion, and dose rate stabilization. An appropriate tolerance should be selected to prevent beam hold-off due to MLC velocity limitations. **Conclusions:** Quantification of patient breathing variability and machine limitations is necessary for safe delivery of 4D-WRT.

SU-FF-J-91

Linear Methods for Hepatic Perfusion Imaging

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Purpose: Hepatic perfusion imaging could be valuable for assessment of therapeutic response and normal tissue toxicity in patients undergoing treatment for hepatic lesions. However, voxel-by-voxel estimation of liver perfusion using non-linear least squares (NLLS) fits of dynamic contrast-enhanced (DCE) CT or MRI data to a compartmental model with dual input functions is a computationally expensive process. The purpose of this study is to develop and evaluate efficiency, stability, and bias of three linear methods for computation of hepatic perfusion parameters. **Method and Materials:** Through simple mathematical manipulation, the single compartmental model is converted into a linear equation (linear in three unknown parameters: arterial perfusion k_a, portal vein perfusion k_p, and the outflow rate k_2). The ordinary least squares (OLS), total least squares (TLS), generalized linear least squares (GLLS), and NLLS methods were used for estimates of the perfusion parameters from simulated data that mimic normal liver perfusion. Gaussian-distributed random noise was added into the theoretic time-contrast concentration curves. The stability and bias of the three parameters were calculated from 5000 simulations as a function of contrast-to-noise ratio of the liver parenchyma, CNR_L, and the temporal sampling interval, Δt, for each of the four methods. **Results:** Dependencies of the stability on CNR_L (varied from 10 to 20) and Δt (1 to 8 seconds) were similar among all four methods, with NLLS and GLLS having slightly better stability. The increase in bias with Δt was greater for NLLS and GLLS than for TLS and OLS, particularly for estimates of k_a. However, the computation time for NLLS was 10-100 times greater than for the linear methods. **Conclusion:** This study suggests that the linear methods can achieve the stability and bias similar to or better than NLLS, but substantially reduce the computation time, making liver perfusion imaging practical for use in clinical trials.

SU-FF-J-92

Measurement of Linear Accelerator Photon Beam Spot Size and Assessment of Its Long-Term Stability

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Purpose: To characterize the beam spot size of Siemens linear accelerators and assess its long-term stability for megavoltage cone-beam CT (MV-CBCT) application. **Method and Materials:** A laminated beam spot camera of length 20 cm was constructed for the measurement of the beam spot size. With the linac gantry at 180°, the camera was positioned on the compensator tray and a Kodak XV film placed on it. An exposure was delivered using photon (6, 10, 18 MV) beams and the FWHM of the resulting source intensity profile used as a measure of the beam spot size. Measurement of the beam spot size was performed in both the gun-target direction (in-plane) and the cross-plane direction for seven Siemens accelerators. To assess the long-term stability of the beam spot size, measurements taken 1 year apart were compared to each other. **Results:** The measured beam spot diameters (FWHM) range from 1.6–2.8 mm. For all accelerators, the in-plane spot size was equal to or larger than the corresponding cross-plane spot size by up to 0.6 mm. Treatment units of the same design had spot sizes that were, in general, not identical but differed by up to 1 mm. Comparison of measurements on the Primus' and Mevatrons showed the introduction of the former (new generation accelerators) did not necessarily lead to a reduction in the spot size. Also, beam spot sizes measured 1 year apart were found to be similar. **Conclusions:** The new accelerator models did not in general provide an improvement in the spot size compared to the old models. Assessment of the long-term stability of the beam spot showed the spot size remains fairly stable over time. However, the observed spot sizes are large in relation to focal spot size of diagnostic x-ray imaging devices, and this might compromise MV-CBCT image quality.

SU-FF-J-93

Mechanical Accuracy of A Robotic Couch

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Purpose: To take full advantage of image guided radiation therapy (IGRT), the target shifts must be done accurately and efficiently. Recently, University of Florida, Radiation Oncology Department has implemented Medical Intelligent HexaPOD™ 6D Robotic Treatment CouchTOP. The purpose of this study is to determine the accuracy and efficiency of the HexaPOD™ CouchTOP system. **Materials and Methods:** The accuracy and efficiency of HexaPOD™ CouchTOP system were evaluated and compared with those of Varian and Elekta couch systems. All three couch systems were displaced in all three Cartesian coordinates and measured by BrainLab ExacTrac infrared (IR) camera system. To determine the efficiency of each couch system, average time spent for couch adjustment was recorded. Since HexaPOD™ system can be rotated with respect to three Cartesian axes, the rotation angular movement was evaluated for the HexaPOD™ system. Because the HexaPOD™ couch's default pivot point is not located at linear accelerator's isocenter, a user defined pivot point had been determined using a simple mathematical relationship. **Results:** For the average time of couch adjustment, 25 sec/1-direction, 60 sec/1-direction and < 20 sec/3-direction were obtained for Varian, Elekta and HexaPOD™ couch systems, respectively. The average displacement differences in lateral direction for Varian, Elekta and HexaPOD™ were 0.33 ± 0.21, 0.33 ± 0.21 and 0.09 ± 0.11 mm, respectively. Similar results were observed for longitudinal and vertical directions. For roll angular movement, HexaPOD™ CouchTOP system was observed to be 0.01 ± 0.01°. Similar results were seen for both pitch and yaw angular directions. **Conclusion:** It is concluded that HexaPOD™ CouchTOP system has the capability to make target shifts to the accuracy of within sub-millimeter and sub-degree with efficiency.

SU-FF-J-94

Metrics for Assessment of Reproducibility of Respiratory Motion for Four-Dimensional Computed Tomography Imaging

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Purpose: Image data sets obtained via four-dimensional (4D) computed tomography (CT) quantify motion of internal anatomy as a function of the patients' unique respiratory cycle. Crucial to the acquisition of high-quality 4D CT data sets is the regularity of the respiratory cycle. The purpose of the present study is to develop metrics that can be used to assess the regularity of respiratory motion, as well as software that can readily extract these metrics from files containing respiratory information generated in a course of 4D CT image data acquisition. **Method and Materials:**
4D CT image data sets from 282 patients were acquired, along with files describing motion of an external fiducial that gathered respiratory patterns. Software was developed to calculate the mean amplitude and standard deviation of the amplitude, the mean period and standard deviation of the period of each respiratory data set, and the cross-correlation of the fiducial amplitude in each respiratory cycle with the mean amplitude. **Results:**
The range of mean amplitudes was 3.45 mm. to 29.26 mm., and the associated standard deviations ranged from 0.04 mm. to 10.64 mm. The mean breathing rates ranged from 2.39 to 10.88 sec., with a range of standard deviations of 0.02 to 10.92 sec. Histograms were generated that relate the various metrics assessed and the variability encountered. The cross-correlation can be readily displayed for each respiratory cycle. **Conclusion:**
The data obtained is thus available to correlate with the quality of the 4D CT images.

SU-FF-J-95

MLC Tracking of Respiration-Induced Target Motion

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Purpose: Respiration induced target motion is a challenge in achieving both target dose coverage and normal tissue sparing in external radiation therapy. This study is to develop a new technique to dynamically track the moving target when delivering either three-dimensional (3D) conformal therapy or intensity modulated radiation therapy (IMRT) for whose patients who can reproduce their recorded breathing pattern under audio/video guidance. **Method and Materials:** 4D-CT scanning is triggered by respiration signal and CT images are sorted into eight respiration phases. After the physician contours the GTVs of the eight CT data sets, the GTVs' centroid positions are measured and the trajectories in the beam's eye-view (BEV) can be calculated. A treatment plan can be generated based on a reference phase CT image with the MLC's travel direction set to the target moving direction. The step-and-shoot MLC segments of the static plan are converted into dynamic segments based on the motion trajectories in the BEV. During the delivery, the beam is turned on at the reference phase and remains on as long as the dynamic MLC segments are in sync with breathing. **Results:** Breathing patterns were successfully deduced from 4D CT images and the motion amplitudes were found varying with the patient and tumor position. A sinusoidal motion pattern was used in the segment conversion for verification purpose. Three films were placed on a phantom moving sinusoidally and were irradiated for the static, tracking, and no-tracking cases, and the film dosimetric study was conducted. As an indication of the dose coverage, Gamma index was measured and found to be 91.1% and 67.9% for the tracking and no-tracking cases, respectively. **Conclusions:** The MLC tracking significantly improves the dose coverage. This technique provides a potential to improve dose conformity when considering the target motion induced by respiration.

SU-FF-J-96

Modeling Correlation Between External Surface Motion and Internal Organ Motion Based On 4DCT

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Purpose: To develop a method for modeling the dynamic relationship between patient surface motion and internal target motion using 4DCT data. Then, to verify its capability to interpolate internal target motion with real-time patient surface motion information. **Methods and Materials:** At discrete phases of a respiration cycle, the coordinates of points in a grid with specific interval on patient surface and internal target were automatically extracted from 4DCT data, then used for the experiments. A radial basis function (RBF) based neural network was employed for modeling purpose. The model was examined by eight sets of data, which consists of the coordinates of points on a patient surface and a region of interest (ROI) on either the left lung or right lung. **Results:** With fine sampling (grid interval < 5 voxels) of the patient surface and internal target, less than 5% interpolation error was found in seven experiments. one patient (right side of left lung) with error more than 8% and unexpected displacement more than 10 mm in 4DCT was observed. Coarse sampling (grid interval >10 voxels) will result in a larger interpolation error. In seven successful cases, the interpolation errors less than 2mm. The only failed one had interpolation error of 4 mm. **Conclusion:** A dynamic model is established for correlating patient surface motion with internal target motion based on 4DCT data. An acceptable interpolation accuracy is achieved for 7 of 8 cases examined in this study. The only failed one implied that for target motion with larger displacement and higher frequency, the model based on 4DCT data might be not sufficient because of its limited time resolution in acquiring those information in a respiration cycle.

SU-FF-J-97

Modeling of Lung Tumor Response to Image-Guided Radiation Therapy

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Purpose: To employ locally weighted regression (LWR) as an empirical technique for modeling tumor response to radiation treatment. Methods and Materials: Daily Megavoltage CT (*MVCT*) images were acquired prior to the delivery of 660 lung treatment fractions for 20 lung cancer patients, with contoured tumor volumes in each image. This data was used to develop a LWR model of the tumor progression throughout the treatment. A leave one out cross validation (*LOOCV*) technique was used to evaluate the performance of the model with varied combinations of days of patient data. For each patient, the model was run using the remaining patient data as training data, but with different test observations for each trial. Multiple simulations using random sampling without replacement were carried out to ensure that all possible combinations were tried. The best combination of days was determined by finding the mean predictive performance. Since this technique will eventually be used to make decisions about a patient's treatment, each prediction was accompanied by a measure of its uncertainty. A large uncertainty value indicates that the prediction is unreliable, most likely due to poor coverage of the training data. **Results:** The LWR model did not always accurately predict the shape of the tumor response curve, but the model was accurate in its predictions made at the end of a patient's treatment. The average prediction error was 13%, and even tumor volume increases during the course of the treatment were correctly predicted. **Conclusions:** The LWR modeling technique proved fast and fairly accurate when predicting the tumor volume at the end of treatment, and improvement is expected as additional data is added to the memory matrix. Future research will use expert opinion and data analysis techniques to determine which additional patient information will improve the model.

SU-FF-J-98

Motion Encoded Beamlets for Optimization and Evaluation in Four-Dimensional (4D) Radiotherapy

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Purpose: To develop a simple model that fully utilizes the information of 4DCT and accurately incorporates *a priori* knowledge of patient motion into plan optimization and evaluation in 4D radiotherapy. **Methods and Materials:** We model the IMRT optimization as two independent schemes, the beamlet dose calculation scheme and the beamlet weights updating scheme. All motion information is encoded in the beamlet dose calculation scheme. A 4DCT is used to calculate beamlet dose associated with each phase. Deformable registration determines the voxel-to-voxel map from the arbitrary phase to the reference phase, which is used to map beamlet dose of the arbitrary phase to the reference phase. A priori knowledge of respiration is modeled as (time-dependant) probability

density function of respiration phases. The motion encoded beamlet (MEB) is the probability-weighted summation of the deformed beamlet of the arbitrary phase. Dose calculation and plan evaluation is always in the reference phase. Beamlet weights updating scheme is same as static optimization. We studied different optimization and delivery schemes in 4D radiotherapy. These studies include static optimization with various margins, free breathing delivery (FBD), gating deliveries (GD) with uncertainty and breathing synchronized delivery (BSD) with uncertainty. **Results:** As for the FBD considered, optimization using MEB show superior DVHs with reduced OAR dose than the margin-based optimization. GD is better than the FBD if proper gating phase is chosen and gating uncertainty is low. BSD is superior to FBD if synchronization is enforced during delivery. On the other hand, FBD shows greater tolerance to delivery uncertainty than GD and BSD method. **Conclusions:** Motion encoding through probability-weighted summation of beamlets is a flexible and powerful technique to incorporate arbitrary patient motion into optimization and evaluation. Through MEB, evaluations of different delivery schemes in 4D radiotherapy can be done in the same framework.

SU-FF-J-99

MR Imaging for Improving IMRT Targeting of Prostate Cancer

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Purpose: To evaluate the role of magnetic resonance imaging (MR) in improving prostate and seminal-vesicles (SV) target localization as well as penile bulb (PB) tissue avoidance in IMRT for prostate cancer. **Method and Materials:** CT and MR planning data for 16 patients treated with IMRT were analyzed retrospectively. The prostate, SV, and PB volumes were delineated on both the CT and MR images while rectum, bladder, femurs and other normal tissue volumes were delineated only on CT images. CT and MR scans were acquired over a 4 hour interval and, the MR scans were registered with the 3D planning CT scans, and consequently the IMRT dose distributions. Dosimeteric parameters and DVHs for the prostate, SV, and PB volumes based on CT-outlined and MR-outlined contours were compared. Furthermore, the areas for potential geometric target underdosing based on MR information were calculated to evaluate the quality of the CT-based plans. **Results:** Analysis revealed that the prostate MR-delineated volumes were smaller than the CT-delineated volumes by 10%-40%. The SV-MR-delineated volumes were larger than the SV-CT-delineated volumes by 25%-100% and, PB-volumes in CT and MR varied up to +/-50%. The prostate mean-dose for CT- and MR-based volumes was within 3%. However, in 4 patients, the minimum-dose to 4-10% of the MR prostate-volume was lower by up to 15% when compared to the CT plan. In 3 of these patients, there was an anterior movement of the prostate because of rectal expansion. The SV-CT-volumes mean- and minimum-dose were lower than the MR-volumes by a maximum of 5%. The PB-CT-volume mean-dose was higher than the PB-MR-volume by a maximum of 10%. **Conclusion:** The quality of the dose delivery can be improved by identifying patient-specific margins based on the CT and MR imaging data thereby potentially allowing further gain in the therapeutic ratio for prostate cancer.

SU-FF-J-100

Normal Tissue Dose in Abdomen Under Dynamic Beam Tracking

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Purpose: Dynamic beam tracking has been proposed for moving targets. Since planning systems consider all structures stationary, the tracking delivery is purposely different from the plan. This study evaluated the dosimetric differences in normal tissue between the stationary beam plan and the dynamic beam delivery. **Method and Materials:** IMRT plans for abdominal cancers were generated without considering organ motion. A margin of 1 cm, rather than the conventional 1.5 to 2cm, was used. The resulting MLC sequences were converted to dynamic sequences to track a hypothetical sinusoidal target motion of ±2cm in superior/inferior direction and ±1.5 cm in anterior/posterior direction. A 4-second respiration cycle and 400 MU/minute dose rate were also assumed. To assess the worst-case scenario of normal tissue dose difference, all normal structures including liver, kidneys, small bowel and spinal cord were assumed stationary. Doses recalculated using the dynamic sequences were compared with that of the original IMRT plan. **Results:** As expected, dynamic beam tracking maintained target dose coverage while substantially reduced doses to surrounding normal structures. The differences in normal tissue dose between the stationary beam plan and the moving beam plan were small. The low-dose volume was increased while the high-dose volume was decreased slightly in normal tissue with dynamic beam tracking. No degradation of normal structure sparing was observed although the structures were not moving with the target. **Conclusion:** Contrary to our intuitions, dynamic beam tracking does not significantly alter the normal tissue dose in the abdomen as compared with optimized plans using stationary beams. Unsynchronized motion between the target and normal structures did not cause higher doses to the normal structures when tracking is focused on the target. MLC sequences of the optimized stationary plans can be used for dynamic beam tracking using a simple conversion into dynamic sequences that follows tumor motion.

SU-FF-J-101

Optimized Field Shaping Strategy for Image Guided Radiation Therapy Treatments

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Purpose: Reducing normal tissue irradiation is one goal of image guided external beam radiation therapy treatments. One approach is to adjust the patient position based on daily imaging so that the target is localized and margins used for setup uncertainty can be reduced. The field shapes are generally determined at the time of simulation based on expansions of the clinical target volume. This work studies whether there are alternative field shaping strategies to reduce the volume of normal tissue in the field given that daily image guided position adjustments will be made. **Method and Materials:** Daily port films were acquired during prostate treatments that used an endorectal balloon for both immobilization and localization of the prostate. The contour of the balloon on lateral films was used to represent the shape of a sensitive structure to be shielded from treatment. The effect of static optimized, static conformal, and adaptive blocking strategies on the area of balloon in the treatment field was studied assuming that a daily image guided shift was allowed before treatment. **Results:** The daily port films of 9 patients were analyzed. The endorectal balloon allows localization of the anterior rectal wall and indicates a variation in shape from day to day. For all patients there are optimal field shapes that include less balloon area in the field than a conformal field shape. Relative to the optimal field shape, conformal, average, and running average field shapes involved 63%, 20% and 22% more balloon in the field. **Conclusion:** For targets of sensitive structures that have interfraction shape changes, image guidance enables non-conformal field shapes to provide better shielding than conformal fields. This blocking strategy may improve treatments without daily field shape adjustments.

SU-FF-J-102

Patient Breathing Motion Synchronized IMAT: A New Technique for Compensating Intra-Fraction Organ Motions

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Purpose: To develop an image-guided radiotherapy technique for compensating intra-fraction organ motions by taking full advantage of 4-D CT and motion tracking. **Methods and Material:** We have developed a new image-guided radiotherapy technique called patient breathing motion-synchronized intensity-modulated arc therapy (IMAT) based on the following observations. (1) If the LINAC gantry rotates x degrees in one breathing cycle during an IMAT arc delivery, then the beam source "sees" the same breathing phase at beam angles spaced x degrees apart. (2) If each breathing cycle is divided into k breathing phases, then we can partition all discrete beam angles used for planning an IMAT treatment into k groups, with each group "seeing" a particular breathing phase. If one can first calculate an intensity map for each group of beam angles using their corresponding snapshot in the 4D CT image set as a gantry-fixed IMRT plan, then the resulting k groups of intensity maps can be combined and converted into a final set of IMAT treatment arcs. As long as the patient can reproduce his/her own pre-recorded breathing patterns, the IMAT plan can be delivered and is optimal in 4-D. (3) To ensure that the patient's breathing is always at the correct breathing phase at the start of the irradiation of each IMAT arc, the beam is not turned on after pressing the "Beam-On" button until the breathing pattern reaches the predetermined phase through motion tracking. **Results:** We applied the motion-

synchronized IMAT technique to the dynamic phantom from CIRS Inc., which can simulate patient breathing motions. Our experimental study indicated that this technique can deliver optimal treatments under motions. **Conclusion:** We have developed a new image-guided radiotherapy technique called patient breathing motion-synchronized IMAT. Our prototype study has demonstrated the feasibility and advantage of this novel method that warrants further investigation.

SU-FF-J-103

Performance of the Nucletron Simulix Evolution Flat-Plate Imaging System and CBCT

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Purpose: To characterize the performance of the flat-plate imaging system available on a commercial radiotherapy simulator, to describe some of it's clinical limitations and to present preliminary results when used in cone-beam CT mode. **Method and Materials:** Measurements were performed on the Nucletron Simulix Evolution simulator installed at our institution. The Simulix Evolution is equipped with a 40 cm x 40 cm flat-panel detector. Low contrast measurements were performed with a CDRAD contrast-detail phantom at the center of varying-thickness slabs of water-equivalent material. Cone-beam CT (CBCT) images were obtained with the AAPM CT and with a 20-cm diameter water phantoms. **Results:** The Simulix Evolution performs digital fluoroscopy at a fixed rate of 3 frames/sec. There is no digital radiography mode available currently. In fluoroscopy, two automatic brightness settings are available (ABS1 and ABS2). Entrance skin exposure levels at time of acceptance exceeded 15 R/min. Contrast-detail measurements with 10-cm and 20-cm water-equivalent phantoms demonstrated that the grid has limited clinical utility since the large air gap present reduces the impact of scatter. Removing the grid reduces patient exposure by a factor of 2. Note that the grid is not used in CBCT. Evaluation of the CBCT mode demonstrated that the system does not currently meet the HU uniformity target of +/– 75 HU for water set by the manufacturer. Ring artifacts are also present and compromise clinical utility. Images and clinical examples will be presented. **Conclusion:** Lack of a digital radiography mode limits the clinical utility of the Simulix Evolution. With optimization, the system can be operated with clinically-acceptable fluoroscopy images at exposures below 5 R/min. Cone-beam CT image quality is currently compromised by the presence of ring artifacts and by poor HU uniformity and low-contrast discrimination.

SU-FF-J-104

Performance of the Philips Gemini GXL PET/CT Simulator

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Purpose: To present results obtained during the acceptance of the Gemini GXL PET/CT Simulator system. **Method and Materials:** A flat radiotherapy tabletop is permanently installed on our system. CT Simulator acceptance was performed using the TG-66 Tables II and III as templates. Two 60-cm long CT Sim phantoms were used. The relative electron density (RED) to HU relationship was measured with the RMI 465 and Catphan 600 phantoms and analysed using the stoichiometric method of Schneider et al. HU uniformity was measured with a 20-cm water phantom and contrast-to-noise (CNR) performance measured with the Catphan. PET performance was measured using the NEMA 2-2001 standard at the factory before shipment and after installation. **Results:** Table sag was measured to be +/- 4 mm over a 1200 mm scan range with loads of 0 to 282 lbs. During longitudinal table displacements, a 2-3 mm shift occurs over a 300 mm range and makes it impractical to use the head-end of the table in some applications. The slice sensitivity profiles for the 0.75 and 1.5 mm nominal slice thickness were measured to be 1.1 and 1.8 mm. From the RMI 465 and Catphan measurements, a RED-HU relationship applicable to biological tissues at 120 and 140 kVp was developed. HU uniformity for water was measured to be +10 HU to -12 HU for clinical protocols. Image quality is evaluated by quantifying the CNR for a 15 mm object. PET peak true count rate and peak NEC rate performance measured at the factory and at installation are below manufacturer published specifications: (191, 182 vs 203 kcps) and (61, 56 vs 70 kcps). **Conclusion:** Future work will involve evaluating PET spatial resolution at 20 cm off-axis positions, quantifying the impact of table load on PET/CT fusion accuracy and developing tools to permit clinical PET/CT simulation.

SU-FF-J-105

Placement of Localization Wires for Breast Surgery Guided by the Positron Emission Mammography

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Objectives: Positron Emission Mammography (PEM) with F18-FDG has been shown to be useful in breast cancer diagnosis and characterization [1]. The ability of PEM to determine breast cancer extent makes it potentially useful for planning surgical excisions. Breast surgery is commonly directed with the use of the hook wires placed under radiological guidance. We sought to develop a method to perform PEM-guided wire localization procedures with image confirmation, which could be used for directing breast conserving surgery. **Materials and Methods:** Five-millimeter lesions with physiologic concentration (0.1uCi/cc) of F18-FDG were implanted into a breast tissue phantom at various locations. Ten-minute PEM scans were performed, and the lesions were located in three dimensions using the PEM tomographic images. 15cm long, 24Ga hollow hook wires filled with a small amount of the F18-FDG (0.1uCi/cm) were guided toward the lesions based on the PEM spatial coordinates. Post-placement scans were acquired to confirm correct placement of the wires relative to the lesion. Placement-accuracy was determined by dissecting the phantom along the wire, and verifying the lesion position relative to the localization wire hook. **Results:** All ten attempts at lesion localization were successful. **Conclusions:** An accurate and practical method of wire localization of breast lesions identified on PEM images was developed and tested on phantoms. **References:** 1. Tafra L et al. Pilot Clinical Trial of 18F-fluorodeoxyglucose Positron-Emission Mammography in the Surgical Management of Breast Cancer. *Am J Surg.* 2005; 190:628-32. **Disclosure:** Authors are employees of the company sponsoring the study.

SU-FF-J-106

Predicted Tumor Motion Ranges During Adaptive SBRT

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Purpose: The purpose of this study is to develop a method to estimate the patient-specific clinical accuracy and safety of adaptive SBRT after treatment delivery. Respiratory motion phantoms rely on continuous knowledge of the in-vivo tumor position, which does not exist for the time needed for adaptive SBRT delivery. A first approximation is to study the tumor motion range as predicted by the adaptive SBRT delivery system during treatment and compare the motion range to published literature. **Method and Materials:** The predicted tumor motion was analyzed for 48 patients with 52 tumors. The database contains 28 tumors in the lung, 4 hilar tumors, 9 pancreases, 2 each in liver and chestwall, and one each renal, retroperineal, and internal mammary nodes. The mean and variance of tumor motion amplitudes were calculated using MatLab. Normal distributions were fitted to a respiratory extrema amplitude histogram. **Results:** The motion ranges for most sites agreed with the literature. The largest motion amplitudes of 12 to 28 mm were observed in the lower lung. Fluctuations about the average motion ranges are mostly small. 50% of tumors in the upper and middle lung and hilum could have been treated without adaptive SRS using 2 mm PTV margin. This would have reduced the risk to patients caused by fiducial placement. The extent of motion in the pancreas is smaller than cited in the literature. **Conclusion:** We analyzed tumor respiratory motion ranges under free breathing during adaptive SBRT. Certain patient subgroups could have been treated with non-adaptive SBRT and therefore with reduced risk from fiducial placement, if the extent of the tumor motion could have been determined before treatment by 4D imaging. Tracking problems due to sub-optimal fiducial placement may lead to problems in tumor motion prediction, which can be discovered by our analysis method after the first treatment.

SU-FF-J-107

Predicting Dosimetric Errors From Real-Time Tumor Tracking Using a Treatment Couch During IMRT Delivery

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Purpose: To determine the dosimetric errors resulting from real-time tumor tracking using a treatment couch-based feedback control system. **Methods:** The couch dynamics and controller were modeled as a closed-loop feedback control system. A real-time tumor trajectory was input into the control system and the resulting output residual tumor motion trajectory was determined as a function of varying parameters (time constants and dead times) used to describe the system dynamics. The residual motion trajectory served as the input for a Monte Carlo superposition dose calculation algorithm that sampled the position of the tumor according to the displacement distribution from the residual tumor trajectory. We considered tumor trajectory data from a lung tumor case and applied it to a 7-field IMRT plan in which the prescribed dose was 66 Gy. The motion influenced dose distributions were compared with the "static" and tumor motion without feedback control cases. **Results:** The fraction of tumor displacements greater than 3 mm for uncontrolled motion was 0.72, 0.32 for the case in which the couch dynamics were described by two equal time constants of 0.135 s and a dead time of 0.27 s and the controller described by a time constant of 0.20 s. For even smaller time constants and dead times, this fraction reduced to < 0.05. The volume of the GTV receiving the prescription dose was 99% for the static case, 68.9% when uncontrolled tumor motion is present and 98.3% when feedback control is employed and the fraction of tumor displacements > 3 mm is 0.32. **Conclusion:** Our results show that real-time tumor tracking may be achieved using a treatment couch with < 2% degradation in tumor volumes receiving the prescribed dose. The motion-influenced dose distributions are more dependent on the distribution of residual tumor displacements than on the maximum instantaneous displacement.

SU-FF-J-108

Predicting Respiratory Waveform of 4D CT Patients Using Moving Least Square Method

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Purpose: The purpose of this study was to predict patient respiratory waveform precisely and quickly using a Moving Least Square method. The external respiratory waveform may have a strong correlation with tumor motion in lung and upper abdomen. Prediction is important because tumor may move significantly during the finite time between monitored position change and beam adjustment. **Method and Materials:** An adaptive linear filter based on the Moving Least Square (MLS) algorithm was used to predict the respiratory waveform signals for six 4D CT patients. The respiratory waveform was acquired with a bellows system at a sampling frequency of 100 Hz or a sampling period of 10 ms. To predict one datum in the future (10 samples or 100 ms away), 10 s history data (1000 samples) were fed to the linear filter to calculate its coefficients with the MLS algorithm. The output of the linear filter was the predicted value. The predicted values were compared to the real data recorded. We also calculated the Root Mean Square Error (RMSE) of the prediction for each patient and normalized it with the average waveform amplitude. The accuracy of MLS method was compared with that of Wiener-Hopf method in the normalized RMSE values. **Results:** For a 100 ms prediction interval, the average prediction RMSE for the 6 patients was 2.1%, with a standard derivation of 0.7%. The computation time for predicting one datum with MLS method was 0.5 ms, which is far less than the sampling period (10 ms). This MLS method shows smaller normalized RMSEs than the Wiener-Hopf method for all 6 patients. **Conclusion:**
The prediction of patient respiratory waveform using MLS method is both accurate and fast. Real time prediction of respiratory waveform and tumor motion is possible.

SU-FF-J-109

Preliminary Study of Deformable Image Registration Using ALE Mesh

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Purpose: It is desirable to preserve mass and topology at every element during deformable image registration. We present some preliminary results using an ALE mesh for deformable image registration of head and neck tumors. **Method and Materials:** Arbitrary Lagrangian-Eulerian (ALE) moving mesh is a finite-element based technique that preserves mass and topology during deformation. The displacement of the moving boundary can propagate to the interior nodes throughout the domain. A smooth mesh deformation can be obtained by solving partial-differential equations (PDEs) for the mesh displacements. We adopted this technique in deformable image registration. The idea of our image registration, currently contour-based, is to generate ALE mesh in a reference image, move the external boundary (or surface) to match the boundary in a target image, and track the contours of the interior organs or tumors, which are deformed by the ALE mesh movement. The software COMSOL Multiphysics (Comsol, Inc., MA) was used. **Results:** The image registration was tested with two-dimensional images, using structure contours of head and neck tumors. Two sets of CT images and structure contours taken before and after chemotherapy, respectively, were used. The external contour obtained before the chemotherapy was moved to match the external contour obtained after the chemotherapy. Displacement vectors of the domain enclosed by the external contour were derived from the moving mesh, which were then examined with the deformation of gross target volume (GTV) contour. A warped GTV contour was obtained by applying the displacement vectors to the GTV obtained before the chemotherapy. The result showed that the warped GTV nearly agreed with the GTV obtained after the chemotherapy, except a small part. **Conclusion:** The preliminary study shows promising application of deformed mesh in image registration. Further studies in three dimensions and comparing the agreements between our methods and elastic-mechanical modeling will be included.

SU-FF-J-110

Quantification of Image Alignment Differences for Tomotherapy Prostate Patients

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Purpose: Accurate registration of MVCT to planning kVCT images is required for daily positioning of patients treated on helical tomotherapy. Due to prostate motion, overlaying the prostate, overlaying the pelvic bones, and finding the best overall image overlap can result in three different alignments for prostate treatments. The objective is to quantify these alignment differences for research patients treated on the TomoTherapy Hi*Art system and determine the suitability of using the latter two alignments to correct for inter-fraction prostate motion. **Method and Materials:** Daily MVCT images have been retrospectively registered to planning images using three different mutual information based algorithms. Each algorithm is designed to produce one of the alignments and does so by using selective planning CT pixels when calculating the mutual information parameter. Depending on the alignment, only prostate pixels (including small margin), bony pixels, or all image pixels are used. To reduce registration uncertainty and eliminate gross miss-registrations, a multi-start optimization procedure with random initial alignments was employed. Offsets between each alignment were calculated for ten prostate patients, each typically having twenty-five fractions. **Results:** Maximum offsets of 6.7mm and 4.9° were observed between the pelvic bone and overall image alignments. Mean translational and rotational deviations were 2.3mm and 1.5° with standard deviations of 1.4mm and 0.7°. Registration resulting in pelvic bone overlap better accounts for prostate motion than using the entire image for alignment purposes. Maximum, mean and standard deviation translational offsets between overlaying the prostate and overlaying pelvic bones are 7.8mm, 2.8mm, and 1.6mm. The respective values for prostate and overall image overlap are 9.3mm, 4.4mm, and 2.1mm. **Conclusion:** Clinically significant offsets between the three image alignments have been observed for tomotherapy prostate patients. Mutual information registration using only bone pixels better accounts for inter-fraction prostate motion than using all image pixels.

SU-FF-J-111

Quantification of Patient Specific Target Motion in the Presence of Limited Data Through Population Models

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Purpose: Integrate 2D cine imaging into 3D patient population models of physiological motion for patient specific quantification of deformation. **Method and Materials:** Inhale and exhale CT images of the liver were obtained for 5 patients under an REB approved protocol. A finite element model was constructed from the exhale contours of one patients liver and deformed into the exhale then inhale position of each patient, providing a common model of the 3D deformation of each patient's respiration, using Morfeus, a finite element-based deformable registration algorithm. Average deformation maps were computed for all combinations of 4 patients. Simulated 2D coronal cine images were generated from the exhale and inhale data of each patient. Narrow 2D channels were used to obtain image intensity data at the dome of the liver and the inferior tip of the liver on the exhale image and at the same location on the inhale image. A least squares fit was performed to align the image intensities in the superior-inferior direction, providing an estimate of the coronal motion of the liver. The motion from the channel was applied to the population deformation model, providing patient specific refinement by scaling the motion of the population model by the ratio of the motion at the navigator for the specific patient to the motion at the navigator for the population model. **Results:** The average superior-inferior displacement difference over the liver volume between the 3D deformation model via Morfeus and the patient-refined population model was –0.12 cm (SD 0.15 cm). The average standard deviation across the five patients was 0.38 cm. **Conclusion:** Population models of volumetric organ deformation due to physiological motion can be used to predict patient specific motion when limited data is available, such as with 2D cine data. **Conflict of Interest:** Research supported in part by Varian Medical Systems

SU-FF-J-112

Radiobiologically Motivated Margin Prescriptions

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Purpose: The celebrated formula of Van Herck et al. prescribes a target margin of at least 2.5 times systematic standard error plus 0.7 times random standard setup error, in order "to ensure a minimum dose to the CTV of 95% for 90% of the patients" (van Herk et al., IJROBP (2000) 47:1121-1135). However, minimum dose is an imprecise and biased surrogate for local control. The question we address is whether this margin formula is consistent with radiobiological principles. **Method and Materials:** To address this issue we make the connection between outcomes and dose distributions using radiobiological modeling and computer simulations of tumor control probability under varying conditions of systematic and random (fraction to fraction) setup errors. We consider an idealized case of a circular cross-section tumor which is shifted systematically and randomly with respect to a fixed dose distribution which falls off rapidly within the plane. Tumor control probability (TCP) is simulated using the Webb-Nahum model. Cohorts of patient treatments were simulated with varying target margins for varying conditions of systematic and random setup shifts. The threshold for a clinically important improvement in TCP was set at 0.01 (absolute). **Results:** The radiobiological simulations consistently indicate that the dose-based Van Herk formula produces margins which are unnecessarily large. In our simulations, margins equal to 1.2 times the setup error + 0.7 times the random error consistently produced TCP values which were within 0.01 of the large margin limit. **Conclusion:** Although the details of the margin prescription depend on the characteristics of the test cases, radiobiological, as opposed to purely dosimetric principles, support using tighter margins around gross tumor volumes than those indicated by the Van Herk equation. This research was partially supported by NIH grant CA85181

SU-FF-J-113

Real Time Tracking of Respiratory Tumor Motion Based On External Respiratory Output

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Purpose: Inability to effectively predict respiratory motion in real-time is a major challenge to account for respiratory motion during radiotherapy. This work aims to develop a novel technique for real-time predicting (tracking) 3D respiratory motion (tumor position and shape change) from external respiratory output (ERO). **Method and Material:** A non-invasive technique, based on the framework known as optimal recursive estimation in signal processing, was developed. Given an optimal filtering algorithm, such as the Kalman filter or the particle filter, the solution of motion tracking is converted to developing proper state and observation models. The state model is a probability density characterizing tumor's motion dynamics. Two types of state model, a conventional motion model and a periodic motion model, were investigated. The observation model is a probability density characterizing the relationship between tumor motion and ERO which can be acquired using a pressure sensor (Anzai) or optical markers (RPM/Varian) place at abdomen. We used the ERO as observation and a conditional Gaussian density as the observation model. The 4DCT datasets of a motion phantom and patients were used to validate the technique. **Results:** The efficacy of our technique was investigated with the phantom and patient data. For each case, state and observation models were constructed by using the "training" 4DCT containing tumor position and shape and corresponding ERO. These models are then applied to "testing data" that contain only ERO to estimate tumor position and shape. Our experimental results showed that the estimated tumor position and shape were consistent with the true position and shape based on the 4DCT acquired with the testing ERO. **Conclusion:** The present technique is capable of effectively tracking 3D respiratory motion in real time. By changing the state and observation models, the technique can be used for a variety of internal motions and real-time external outputs.

SU-FF-J-114

Reduction of Respiratory Motion Using Diaphragm Compression and Gating for Hypofractionated Radiotherapy of Lung and Liver Cancer

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Purpose: Hypofractionated radiotherapy for lung and liver cancer has received great attention recently because of possible improved efficacy and convenient treatment length. Respiratory motion presents a special challenge, as hypofractionated radiotherapy requires a high level of confidence in image targeting and delivery. This study evaluates reduction of respiratory motion using combined diaphragm compression and gating. **Method and Materials:** Patients received either 45 or 60 Gy in 3 fractions. Patients were immobilized with customized Alpha Cradles body cast and a vac bag on abdomen and pelvis. The vac bag served for diaphragm compression and position immobilization. Gated CT data were first acquired at the end-of-expiration and then at the end-of-inspiration 30 minutes later using a commercial gating system. These two CT data sets were registered and positional changes in target were evaluated to estimate residual target motion during gating using scaling factor derived from external marker motion track and gating amplitude. Portal images were acquired for each fraction using manual gating at the end-of-expiration with the guide of the gating system. **Results:** In this ongoing study, we have treated 3 lung cancer and 2 liver cancer patients. The mean difference in CT lung volume between end-of-expiration and end-of-inspiration was 10.5% (range 7.7- 15.5%). The mean differences in position of GTV mass center was 1.5 (range 0.2-2.9 mm) in lateral, 3.3 (range 1.3-7.4 mm) in anterior-posterior, 3.5 (range 0.4-9.0 mm) in superior-inferior. The residual target motion during gating was 0.5 (range 0.1-1.0 mm) in lateral, 1.1 (range 0.4-2.4 mm) in anterior-posterior, 1.1 (range 0.2-3.0 mm) in superior-inferior. For tumors visualized in portal images, target-to-lung positions were reproducible in 2 mm. **Conclusion:** Combined with diaphragm compression and gating and daily imaging, respiratory motion has been effectively reduced to a minimal residual motion during gating, suggesting that CTV-PTV margin reduction may be feasible.

SU-FF-J-115

Registering the Planning CT to the Treatment Geometry in IGRT, Using a Limited Reconstructed Volume Derived From Planar Images

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A set of megavoltage (MV) and kilovoltage (kV) images are obtained during a patient's image-guided radiotherapy treatment (IGRT). The kV images are acquired prior to treating the fields using an on-board x-ray imager. However, The MV images can be acquired both prior and during the actual treatments. Fan-beam reconstruction of back-projected kV images obtained at four or more gantry angles can be used to orient the planning CT to match the treatment geometry. Registering the planning CT to the treatment geometry is necessary if one is to perform dose reconstruction using the multi-planar images and the planning CT, in the absence of a cone beam CT. The MV and kV images provide the exit fluence information for 3D dose reconstruction. Using these 2D treatment images along with the 3D planning CT volume provides adequate information about the treatment anatomy that is needed for the dose reconstruction process. This system might alleviate the need for cone beam CT for patient positioning and/or dose reconstruction. The planar treatment images provide adequately sampled sinogram planes in the spatial dimension, but not in the radial direction. Nonetheless, there is enough data in the sinogram space for registering the treatment geometry to the planning CT. Canny edge finding method is used to decipher anatomical structure in the limited reconstructed volume as well as in the CT volume. This technique can detect both strong and weak edges; and it is less likely than the other edge finding techniques to be fooled by noise. The resulting edge maps are registered to each other by affine transformations. The transformation matrices are then applied to the CT volume in order to register it to the treatment geometry.

SU-FF-J-116

Registration of X-Ray Portal Images with 4DCT DRRs for Patient Setup Verification

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Purpose: To provide a noninvasive method for both setup verification of 4DCT treatment planning and isocenter positioning shifts for treatment delivery. **Method and Materials:** A ten phase 4DCT treatment planning study of the patient was acquired using a respiratory gating system. When the patient was on the treatment couch, multiple on board x-ray images were taken in the anterior-posterior (AP) and lateral directions. An intensity based rigid registration algorithm was applied to obtain optimal shifts in the x, y and z directions. First, a digitally reconstructed radiograph (DRR) using ray-casting algorithm was computed from one of the ten phases of the 4DCT. The correlation coefficient (CC) between the DRR and the x-ray image was then calculated. The 4DCT volume was shifted and new DRRs were generated until the maximum CC value was reached through an optimization process. This procedure was repeated for all ten 4DCT phases. **Results:** Registration of each phase of the 4DCT with the x-ray image provided ten maximum CC values. These values exhibited a single maximum at the phase corresponding to the breathing phase when the x-ray image was taken. The corresponding isocenter positioning shifts for treatment delivery were also obtained. The robustness of our algorithm was demonstrated by registering x-ray images taken at five random phases to 4DCT. The resulting isocenter shifts were consistent between all phases. The standard deviations of the shifts determined for the AP x-rays were 2 mm (lateral), 5 mm (anterior-posterior), and 2 mm (superior-inferior). **Conclusion:** Using only the RPM system, one cannot be certain that the internal anatomy is consistent between 4DCT acquisition and any particular treatment day. Our noninvasive method accounts for internal organ motion and may be used for daily 4DCT treatment setup verification and isocenter positioning.

SU-FF-J-117

Respiration Monitoring Using Radiotherapy Treatment Beam

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Purpose: Real-time monitoring intra-fraction motion is essential for four-dimensional (4D) radiotherapy. Surrogate-based and internal-fiducial-based methods may suffer from drawbacks such as false correlations, being invasive, delivering extra patient radiation, or require additional hardware. We developed a non-surrogate, non-invasive method to real time monitor respiratory motion during radiotherapy treatments. This method directly utilizes the treatment beam and thus imposes no extra radiation to the patient. **Method and Materials:** The method requires a real time detector system and a 4DCT image. The basic idea is to correlate the real-time measured detector signal from the treatment beam with the pre-calculated signals assuming that beam passed through the different phase of 4DCT image. The on-line processes only involve detector signal readout, and 1D correlation of the measured signal with the pre-calculated signals. The respiration phase is determined as the position of peak correlation. The method was tested with extensive simulations based on a 4DCT of a lung cancer patient. Three different IMRT delivery fluence maps were used. Three arbitrary breathing patterns and two dose levels, 2Gy/fraction and 2cGy/fraction, were used to study the robustness of this method against detector quantum noise. **Results:** For the 2Gy/fraction simulations, the respiration phases were accurately determined in real-time for most projections of the treatment, except for a few projections in which beam intensities were extremely low. At 2cGy/fraction dose level, the method can still determine the respiration phase very well with only about 5% of projections having errors greater than 1 phase (0.5 second). **Conclusion:** It is demonstrated that our method can monitor the respiratory motion within +/-1 phase in real time. This method can be easily implemented in any radiotherapy machine with high speed detector system. The motion information obtained can be used to either verify or correct the treatment delivery in real-time.

SU-FF-J-118

Respiration Phase-Based Cone-Beam Computed Tomography (CBCT) Reconstruction

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Purpose: To develop a method to reconstruct CBCT data based on projection data acquired at a specific respiration phase. Methods and Materials: The original projection data were acquired using an on-board imager (OBI) (Varian Medical Systems) over scanning angles from 0° to 360° with 0.5° interval. During the retrospective process, the diaphragm location on each projection image was identified by contrasting the surrounding anatomies. Based on the location of the diaphragm in different respiration phases, the projection data were categorized into respective subsets. Subsequently, the CBCT was reconstructed from the projection data in each subset, using a Feldkamp CBCT reconstruction algorithm. **Results:** The CBCT was reconstructed based on a subset of projection data (single sampling) acquired at the end point of exhalation, which shows the least motion of the diaphragm. In addition, as an extension, the neighboring 1 or 2 projections were also included in the reconstruction scheme (multiple sampling). The preliminary results show that with a single sampling scheme, the reconstructed CBCT image quality is coarse but the implanted staple and bony structures are clearer. When multiple sampling schemes were used, the image quality is better but with increased blurring effect and motion artifact. **Conclusion:** Compared with CBCT conventionally reconstructed for full scan images, the phase-based CBCT provided a sub-optimal option for clinical use. Although the image were imperfectly reconstructed due to the substantially decreased number of projections, a significant reduction of radiation exposure, improvement on blurring and motion artifacts is achieved. In the future, the synchronized respiratory signal (such as RPM signal) could be used to sort the projections for this purpose. This study is partially supported by Varian research grant

SU-FF-J-119

Respiratory Gating with Gantry Mounted Fluoroscopic Imaging

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Purpose: To perform respiratory-gated treatment based on the position of implanted markers in fluoroscopy using a gantry mounted x-ray imaging system. **Method and Material:** We have designed hardware and software capable of gated treatment using the position of implanted markers. The system tracks the position of the marker in real-time using fluoroscopic imaging. Tracking can be done in a single image, for 2D position

information, or can be done simultaneously in a pair of orthogonal images, for 3D position information. When the marker is in the treatment window, the linear accelerator is signaled to deliver the beam. A live display of the fluoroscopy is used to initiate tracking, and to verify tracking and gating operation. **Results:** Gated treatment was performed on a moving phantom, with 3 cm peak-to-peak motion and a 4 mm gating window for internal motion. Fluoroscopy was acquired at a rate of 7.5 frames per second. The system latency from image acquisition to gating was roughly estimated to be approximately 50 ms. Gating operation was tested by delivering 4x4 cm open fields, and tracking the position of a 2mm steel marker in fluoroscopy. This initial position of the marker was assigned interactively. Treatment was delivered successfully for each field, despite some image degradation due to scatter from the MV treatment beam. The dosimetry of the gated treatment was measured in film, and compares well with the non-gated treatment of a static phantom. **Conflict of Interest:** Research sponsored by Varian Medical Systems.

SU-FF-J-120

Results of a Multi-Institutional Benchmark Test for Cranial CT/MR Image Registration

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Purpose: To assess variability in CT/MR image registration results using a benchmark case developed by the Quality Assurance Review Center. The benchmark was developed to credential institutions for participation in Children's Oncology Group Protocol ACNS0221 for treatment of low-grade glioma. **Method and Materials:** Two DICOM image sets were provided. The MR scan had a small target in the posterior occipital lobe that was readily visible on two slices. The lesion was not visible on the CT scan, which was obtained with the patient in a BRW head frame. Each institution was asked to register the two scans using whatever software system and method it would ordinarily use for such a case, to outline the target volume on the two MR slices, and to report the coordinates of the center of the target in the CT coordinate system. To establish a common reference point, the coordinates of the center of the largest BRW rod on the most inferior CT slice were to be reported. Acceptability criteria are based on results from the first 17 submissions. The average of all submissions was used to determine the "true" center of the target. **Results:** Results are reported from 31 submissions representing 26 institutions and 10 software systems. One standard deviation in the position of the center of the target is 1.9 mm. The least variation is in the lateral direction. There was no correlation of deviation with method of registration, i.e. automatic, manual, or match points. **Conclusion:** When MR and CT scans of the head are registered with currently available software, there is inherent uncertainty. This uncertainty of approximately 2mm should be accounted for when defining the PTVs and the PRVs for organs at risk on registered image sets. This work was supported by NCI-H Grant 5U10CA02951.

SU-FF-J-121

Retrospective Analysis of Prostate Cancer Patients with Fiducial Gold Markers Using a Real-Time Tumor Tracking System

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Purpose: The aim of this study was to measure interfraction and intrafraction motion of the prostate during the course of radiation treatment using a real-time tumor tracking system (RTRT-system) and gold fiducial markers. **Method and Materials:** Fifty-five patients underwent implantation with three 2-mm gold markers in the prostate before IMRT treatment planning CT scans. Using a RTRT-system, fluoroscopic images were taken after a) skin-based patient's positioning and b) translational repositioning by moving a couch after a calculation of actual and planned positions of three gold markers. Intrafraction as well as interfraction translation and rotations were analyzed along the three axes (right-left[RL], cranio-caudal[CC], antero-posterior[AP]). Systematic and random errors were computed for these translations and rotations in (a)conventional setup and (b)RTRT setup. To determine adequate margins for these setup, van Herks's formula of $(2.5\Sigma+0.7\sigma)$ were used. **Results:** Without consideration of interfraction errors, prostate treatment would have required average margin of 9.8, 14.3 and 12.5mm (n=1466) about the right-left(RL), craniao-caudal(CC), and antero-posterior(AP) directions, respectively for skin-based patient's positioning. Interfractional random rotation error was 5.9°(systematic error, 8.6°) around RL axis, 3.1°(systematic error, 5.5°) around CC axis, and 5.1°(systematic error, 5.4°) around AP axis. Inclusion of intrafraction movement increases these margins to 11.0, 15.3, and 13.1mm, respectively (n=2905). Intrafractional and inter-beam adjustment further reduced margins to an average of 2.1, 2.5 and 2.3mm, respectively, based on a threshold of 3mm for each direction. **Conclusion:** Monitoring and correction of the intrafraction movement for prostate treatment using this system, significant reduction of margins would have achieved. However, the interfraction as well as intrafraction rotations of the prostate should be taken into account for the additional margins because their magnitudes are not negligible. **Conflict of Interest:** The authors indicated no potential conflicts of interest.

SU-FF-J-122

Systematic Study of Inter-Fractional Variations for Anatomic Sites From Head to Feet.

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Purpose: Inter-fractional variations in patient set-up and anatomic changes are usually site specific. This work aims to systematically study these inter-fractional variations for anatomic sites from head to feet based on the daily MV CT images collected using helical tomotherapy. **Methods and Materials:** A total of first 51 patients treated at various anatomic sites using a helical tomotherapy system (Hi-Art, Tomotherapy Inc.) were analyzed. Daily Tomotherapy MV CT acquired prior to each treatment were used to correct for daily setup error online. A total of 6120 translational shifts and rotational corrections were performed for the 51 patients. The daily serial MV CT and the planning CT were also used to determine inter-fractional anatomic changes off-line. The data for three representative patient cases, pancreas, uterus, and soft tissue sarcoma, are presented. **Results:** Inter-fractional set up errors in skull, brain, and head and neck are significantly smaller than those in chest, abdomen/pelvic, and extremity. The translational shifts are mostly within 3 mm in skull, brain, and head and neck, while they are within 6 mm for other sites. The inter-fractional anatomic changes were significant. For example, during the course of treatment, the pancreas moved up to ±20 mm, and volumes of the uterus and sarcoma varied up to 30% and 100%, respectively. **Conclusions:** The inter-fractional variations in patient setup and in shapes, sizes and positions of both targets and normal structures can be significant and are site specific. The helical Tomotherapy technology has the capability of quantifying and addressing these variations. The data presented in this work dealing with several anatomic sites may be useful in developing adaptive radiotherapy.

SU-FF-J-123

The Effect of Respiratory Motion On Two Breast Radiotherapy Techniques: A Phantom Study

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Purpose: Many centers are looking beyond conventional wedged tangential fields for the treatment of breast cancer by using intensity modulation techniques for improvements in the dose distribution, reduced late tissue toxicity, and improved cosmesis. The improvement in dose uniformity may be mitigated in the presence of respiratory motion. We have compared a forward planned intensity modulated technique with a conventional wedged tangent approach for irradiation of the whole breast. The purpose of this study was to compare these techniques under both static and dynamic conditions to simulate the effect of respiratory motion. **Method and Materials:** We planned these two techniques (conventional wedged tangents and forward planned intensity modulated) on a stationary beeswax breast phantom containing a cork lung insert, using a CT acquired 3D dataset. Treatments were performed with the phantom stationary, and mounted on a moving platform having a sinusoidal waveform. The resulting dose distributions were measured using radiographic film in the anterior-posterior (AP) and medial-lateral (ML) directions. The amplitude of motion and angle of tilt of the breast, representing the relative contributions of the cranio-caudal (CC) and AP components of breathing motion, were varied. **Results:** The dose distributions for the conventional and forward planned techniques were not significantly affected by motion in both the CC and ML directions, for 1cm and 2cm amplitude, and tilt

angles of 15, 30 or 45 degrees. This can be explained as the majority of dose is delivered through open fields, with only a small modulation component using MLCs for forward planning. **Conclusion:** This study demonstrates negligible differences in dose distribution with conventional and simple forward-planned IMRT techniques. The dosimetric benefits of forward planned 3D compensated breast radiotherapy are not adversely affected by respiratory motion.

SU-FF-J-124

The Hounsfield Unit (HU) Accuracy in Varian's Cone-Beam CT (CBCT) and Its Effect On Dosimetric Verification

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Purpose: To evaluate the HU accuracy of Varian's on board CBCT and its effect on the accuracy of dose calculation for dosimetric verification. **Methods and Materials:** A mini CT QC phantom (15cm diameter, 2cm thickness) with different inserts (2cm diameter) of known electron densities was embedded into an IMRT QA phantom to form a body phantom and scanned using CBCT. The scan was acquired in half-fan and pulsed-fluoro mode with a half bowtie mounted. A technical setting of 125kV, 80mA and 25ms was used. The HU for each insert was measured and the HU-ED curve for CBCT was obtained. After that, a Rando pelvic phantom was scanned with both CBCT and SIM-CT using nearly the same KV. The two sets of CT were fused so that SSD at any beam direction agree to 1mm. In this way, the structures drawn in SIM-CT (to simulate prostate treatment) can be exactly transferred to CBCT. Without inhomgeneity correction; the two sets of CT generate exactly the same plan. With inhomogeneity correction, the dosimetric difference was mainly from the HU difference. **Results:** The average HU difference between CBCT and SIM-CT is ~50 but the standard deviation of HU in CBCT is 3-4 times higher. Due to higher beam hardening effect in CBCT, the HU at phantom center is 60-80 higher than that at edges. There is also a ring artifact of 20cm diameter and 1.5cm broad in which the HU is 200 lower. Even though, the dosimetric difference with inhomogeneity correction is relatively small. The minimum dose, maximum dose and mean dose etc. for any structure generally agrees within ~2-5% between the CBCT plan and the SIM-CT plan. The CBCT plan is ~2% hotter at the phantom center. **Conclusions:** Dosimetric difference between CBCT and SIM-CT is ~2-5% due to the inaccurate HU in CBCT.

SU-FF-J-125

Therapy Assessment Using a Full Time Point (fTP) Pharmacokinetic Analysis of Dynamic Contrast-Enhanced Magnetic Resonance Imaging (DCE-MRI): Role of Region of Interest (ROI) Selection in Three Tumor Sites

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Background: DCE-MRI has great potential to provide routine assessment of cancer treatment response. The contrast agent preferentially accumulates in tumors due to increased tumor vascular permeability. The MR based parameters that can be used for treatment assessment (permeability and leakage space) can be averaged over the whole tumor or over a maximum enhancement ROI. The optimal method of analysis is controversial. **Material and Methods:** DCE-MR images of selective head and neck, breast and extremity sarcoma patients were acquired on a 1.5T GE Signa Exite scanner before and after different therapy regimens (concurrent chemoradiation for head and neck, neoadjuvant and hyperthermia for breast, and radiation and hyperthermia for extremity sarcomas). The images were analyzed using an fTP pharmacokinetic analysis implemented by CAD Sciences® (White Plains, NY) that determines the tumor's permeability (PERM) and extracellular volume fraction (EVF). ROIs were defined over the entire extent of the tumor (Tumor ROI) and over areas that show maximum enhancement (MaxEnhROI). For head and neck cases, MaxEnhROI were carefully selected not to include fast enhancing arteries which can bias the averaging. **Results:** For all three tumor types, the trends of PERM and EVF change are the same, but the absolute changes are not. Larger differences are seen in tumors that have peripheral enhancement and large necrotic areas (found often in head and neck and extremity sarcomas). As expected, for homogeneous enhancing tumors (rarely encountered), the differences are not significant. **Conclusions:** Preliminary results show that ROI selection is important in MR parameter averaging, particularly if the quantitative analysis is used for therapy assessment. This statement is true for all the three sites considered. Although DCE-MRI has great potential to provide routine assessment of cancer treatment response, its widespread application should be standardized for clinical use. Supported in part by grant NCI CA42745.

SU-FF-J-126

Treatment of Moving Targets with Scanned Ion Beams: A Comparison of Different Strategies

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Purpose: To compare internal target volume (ITV), gating, rescanning, and motion compensation (tracking) for treating moving targets with a scanned carbon ion beam based on time-resolved computed tomography (4DCT) data for 4 patients. **Method and Materials:** The GSI treatment planning system TRiP has been extended to calculate dose distributions in the presence of motion. Calculations are based on 4DCT data and corresponding deformation maps. To account for respiratory target motion and time dependent irradiation with a scanned carbon ion pencil beam, the treatment plan is temporally divided into sub-plans. Treatment plans were generated for 4 lung-tumor patients. Each plan consists of 1 field to the CTV with margins appropriate for tumor motion. For each patient and technique, 12 combinations of respiratory period and initial breathing phase were studied. Total dose distributions under respiratory motion were compared to a reference treatment plan at end-exhale (without motion) by dose volume histograms and mean lung doses. **Results:** The ITV concept showed severe misdosage caused by interplay between target motion and scanned ion beam. Gating, rescanning (30x), and motion compensation resulted in adequate target coverage for all patients. In comparison to the reference, mean lung dose was similar for motion compensation, but increased by 10-15% for gating, and by ~40% for rescanning. **Conclusion:** An ITV treatment strategy results in severe under- and over-dosage of moving targets. Gating, rescanning, and motion compensation assure target coverage. Mean lung dose is increased for gating and rescanning.

SU-FF-J-127

Two-Dimesional Analysis of Patient Cervical Spine Movement Pattern During Radiation Therapy

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Purpose: To characterize the two dimensional movement pattern of cervical spine during head and neck radiation treatment with the aim to adaptively modify the treatment. **Method and Materials:** An intensity based algorithm was used to extract the vertebrae contours in both diagnosis CT and treatment planning CT images. Vertebrae movement variables were characterized by superimposing segmented sagital CT images using a localized linear conformal registration. The correlation coefficient was used as a method of measuring the similarity for registration. Relative 2-D motion of cervical spine were characterized by a transformation matrix representing motion relative to the adjacent vertebrae with 3 degrees of freedom by rigid body Euler angle and translations of orthogonal coordinate system. **Results:** We demonstrated that an intensity-based local linear conformal registration can be used accurately co-registered cervical spine in the treatment planning CT images acquired before the treatment and in the diagnosis CT images. A large variation was observed in the transformation matrix. The mean absolute Euler rotation of vertebrae were 25.4º for C2, 18.9º for C3, 13.7º for C4, 11.3º for C5, 5.3º for C6 and 7.6º for C7. **Conclusion:** We have quantitatively analyzed the intervertebral motions of the cervical spine during the radiation treatment. We have documented the first accurate depictions of cervical spine coupled motion. This information can be used for treatment planning in an adaptive CT-guided radiation therapy.

SU-FF-J-128

Uncertainties in Target Volume Surrogates in Image Guided External Beam Partial Breast Irradiation

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Purpose: Two methods of image guidance for external beam partial breast irradiation (PBI) are under investigation: kilovoltage (kV) imaging and video-based three-dimensional (3D) surface imaging. Kilovoltage imaging utilizes implanted clips as surrogates for the target volume (seroma). Surface imaging uses the breast surface as a surrogate for the target volume. This study investigates the uncertainties present when utilizing such surrogates in image-guided external beam PBI. **Method and Materials:** Patients were treated on a linear accelerator with dual gantry-mounted kV imagers. Patients were initially aligned using lasers, and simultaneous orthogonal kV images were taken prior to each fraction to correct the setup. Setup corrections were calculated using software that registered the clips in the daily images with their corresponding positions in digitally reconstructed radiographs. Clip migration was examined by quantifying variations in the position of individual clips relative to the center of mass of all clips. Surface video images were also taken for each treatment. The breast surface from each treatment position was registered to the reference surface. Surface deformations were quantified by calculating the distribution of position differences for each vertex on the 3D surface. **Results:** The standard deviation in individual clip positions ranged from less than 1 mm to as much as 2 mm. For the surface deformation, the mean difference between surface vertices was 0.6 mm (range 0.4 to 1.0 mm). The standard deviation of the distribution of surface differences, used as a measure of the distribution width, ranged from 0.5 mm to 1.2 mm. The amount of deformation of the breast did correlate with breast size. **Conclusion:** The uncertainties in target volume surrogates for both clip-based kV imaging and video-based surface matching are small, typically on the order of a few mm. The precision of these surrogates indicates that they can reliably be used for image-guided treatment.

SU-FF-J-129

Using Cone Beam CT to Investigate the Local Geometrical Uncertainties During Head and Neck Radiation Therapy

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Purpose: To develop a model to quantify the local displacements, rotations and deformations in head and neck during the treatment course using Cone Beam CT (CBCT). **Methods:** Five patients underwent weekly CBCTs, immobilized in head and shoulder thermoplastic masks (MedTech®, Orange City, USA). CBCT images were registered to the planning CT by matching the clivus and occipital bone. Eight points located at visibly distinguishable bony landmarks in the head were identified on all images. The displacements of the CBCT points relative to the CT were computed. Head rotation was calculated from the angular change of a plane constituted by three rigid bony points. The spinal canal was contoured in all the image sets and the geometrical centroid line was used as the cord surrogate. The cord deformation relative to the CT was quantified by the variation of the centroid lines.
Results: The means of the inter-fraction displacements, varied between -0.3 and 0.3 cm (standard deviations range from 0.02 to 0.3 cm), for all bony landmark points of each patient. Centrally located points have smaller displacements (mean between -0.1 to 0.1 cm) than circumferential points. The inter-fraction average head spin (rotation in axial plane) was 2 degrees, while the rotations in the saggital and coronal planes were 4 degrees on average. Cord deformation was minimal superiorly (mean ranged over -0.1 to 0.1 cm) and increased inferiorly to the range of -0.3 to 0.4 cm (standard deviation, 0.3 cm). The deformation was larger in the sagittal plane than in the coronal plane.**Conclusion:** Sequential CBCTs enable the analysis of the spatial displacements in the head and neck. This method can be used to develop localized treatment margins for this patient population and immobilization technique.

SU-FF-J-130

Validation of Non-Linear Image Registration-Based Correction Method for Motion Artifacts in 4D-CT

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Purpose: Motion artifacts in CT can be reduced by using 4D-CT acquisition techniques where image slices are retrospectively binned according to breathing phase as determined by a breathing trace. However, motion artifacts may still occur due to breathing irregularities. Such artifacts affect organ delineation and lead to complications when using 4D CT data for dose calculation and accumulation. We propose a method for correcting such artifacts by temporal interpolation using non-linear image registration. **Method and Materials:** The ANIMAL non-linear image registration algorithm was used to determine the transformation between artifact-free phases adjacent to the phase containing the motion artifacts. The weighting factor which, when applied to the transformation, most closely reconstructs the anatomy at the phase to be corrected was determined. CT values in regions of the image containing the artifacts were then replaced with the corresponding CT values from the reconstructed image. The accuracy of the temporal interpolation method was evaluated by simulating motion artifacts resulting from different breathing amplitudes using the NCAT numerical breathing phantom for which the artifact-free image is available by definition. The reconstructed image was compared to the artifact-free image. The temporal interpolation method was applied to correct motion artifacts in patient 4D CT data and the corrected images were compared to physician-delineated contours. **Results:** Correlation between the NCAT phantom images with and without artifacts was improved from 0.971 to 0.992 after correction of the artifacts by temporal interpolation. The quality of the patient 4D CT data was improved after temporal interpolation and the reconstructed anatomy was consistent with manual contours. **Conclusion:** We have developed a method for reconstructing anatomy on 4D CT images in the presence of motion artifacts. The temporal interpolation method was demonstrated to reduce the appearance of these artifacts and therefore improve the accuracy of organ delineation and dose calculation.

SU-FF-J-131

Is There a Relationship Between Body Mass Index, Treatment Set-Up Errors, and the Development of Myocardial Perfusion Defects Following Radiation Therapy for Left-Sided Breast Cancer?

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Purpose: To assess whether body mass index (BMI) affects the rate of "deep" set-up errors (i.e. those that increase the volume of heart irradiated), resulting in an increased risk of RT-induced myocardial perfusion defects (PD) 6-60 months post-RT. **Materials and Methods:** For 87 patients receiving RT for left-sided breast cancer, treatment set-up accuracy was determined by measuring the height of the lung shadow seen at the level of the central axis on simulation and serial medial tangent portal films. SPECT nuclear medicine scans were performed serially pre- and post-RT to assess for cardiac PD. The interaction among BMI, set-up error frequency, and the rate of PD was compared using a 1-tailed Fisher's Exact Test. **Results:** The rates of deep set-up deviations were 9/32 vs. 24/51 in patients with BMI<25 kg/m^2 and ≥25 kg/m^2, respectively (p=0.068) (Fig 1). When patients were stratified by volume of left ventricle (% LV) in the RT field, set-up deviations had an impact on the rate of PD in patients with >0% but ≤1% LV in the field (i.e. patients who are generally predicted to be at very low risk for RT-induced cardiac dysfunction). The rates of PD in these patients with deep vs. "shallow" set-up errors (i.e. those that decrease the volume of heart irradiated) were 5/6 vs. 3/10 (p=0.059) (Fig 2). **Conclusions:** Patients with BMI≥25 kg/m^2 tend to have a higher incidence of deep set-up errors, causing more heart to be irradiated than intended. In patients with very small volumes of heart in the RT field, those with deep set-up errors are more likely to have PD post-RT. Accurate patient set-up on the treatment machine is critical to minimize the risk of RT-induced cardiac injury, particularly in overweight and obese patients. Supported by grants 17-98-1-8071 and BC010663 from the DOD.

Exhibit Hall F

General Poster Discussion
Therapy

SU-FF-T-01

A Delivery Transfer Function (DTF) Analysis of Helical Tomotherapy

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Purpose: Explore the delivery resolution (blurring) for any given beamlet for a helical tomotherapy unit. Based on this analysis, then to determine how the optimization procedure can be further improved to account for the source motion blurring inherent to the unique intensity modulation method used. Also, organ motion blurring effects can be evaluated in this context. **Method and Materials:** We rely upon and expand previous theoretical work of the "Delivery Transfer Function (DTF)" [K. Otto, *et al*., Med. Phys. **29**, 1823 (2002)] to include the unique intensity modulation method of helical tomotherapy. In addition to the collimation of each beamlet, and the Gaussian convolution spreading of the dose that other radiotherapy units have, helical tomotherapy used small arcs of varying lengths to adjust the intensity. The blurring from these arcs are not taken into account in the current Hi-ART® TomoTherapy device. **Results:** Near the isocenter, the transverse (to a given beam direction) blurring is small but at larger radii, the source blurring dominates over leaf size. The longitudinal blurring is dominated by the jaw width, and organ motion blurring less than this width will not be noticed. When a large number of angles are averaged together and with the varying intensities of a real sinogram, the average blurring is very close to the leaf width value >~ 6.5 mm for typical parameters – even well off-axis where source motion blurring will be larger. **Conclusion:** The treatment planning which does not include this source motion can be improved by adding a penalty to beamlets that give large blurring at a particular voxel. Organ motion blurring effects may not seem as deleterious in the context. The averaging effects of many beam directions and many leaf intensities reduces the overall transverse blurring to a very low level for typical situations.

SU-FF-T-02

Comparison of the Dosimetric Properties of Standard MOSFET and MicroMOSFET with Home Made Phantom

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Purpose: To evaluate dosimetric properties of a standard MOSFET in comparison with a microMOSFET **Method and Materials:** We developed the phantoms to perform a calibration and to analyze characteristics of standard MOSFET and microMOSFET. The phantoms are made of polystyrene, which have the shape of semi-sphere with 10cm diameters and flat slab of 30×30cm^2 with 1cm thickness. The slab phantom was used for calibration and characterization measurements such as reproducibility, linearity and dose rate dependence. The semi-sphere phantom was used for angular and directional dependence on the types of MOSFETs. The measurements were conducted at a depth of 1.5cm under 10×10cm^2 fields at 100cm SSD for reproducibility, linearity, and dose rate dependence. For calibration and reproducibility, five standard MOSFETs and microMOSFETs were repeatedly irradiated by 200cGy three times. Dose linearity was evaluated in the range of 10 to 600cGy. The effect of dose rate was also investigated by 200cGy from 100 to 600MU/min. For angular and directional dependence, the measurements were performed between 0° and 90° gantry angles, while MOSFETs were placed at the center of semi-sphere phantom. The 50cGy was irradiated repeatedly three times under same setup. **Results:** The average calibration factor was 1.1±0.95 for standard MOSFETs and 1.09±0.50 for microMOSFETs. The response of reproducibility in the two types of MOSFETs was found to be maximum 0.5% variation. In linearity, the results showed good linear response with R^2 value of 0.997 and 0.999. The angular and directional dependence was found to be within ±2~5% and ±7~8%. **Conclusion:** Standard MOSFET and microMOSFET were compared by the dosimetric characteristics with the home-made phantom. For linearity, reproducibility and calibration factor, two types of MOSFETs showed similar results. On the other hand, standard MOSFET and microMOSFET were found to be remarkable difference due to its detection area size in angular and directional dependence.

SU-FF-T-03

3-D Dosimetric Evaluation On Isocenter Positioning Error in the Dynamic Arc Stereotactic Radiotherapy Based On Optical CT Based Polymer Gel Dosimetry

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Purpose: Accurate isocenter positioning is very important for patient setup in the treatment of stereotactic radiosurgery. In this study, the effect of positioning error of the planned isocenter on the 3-D dose distribution was evaluated for brain lesions treated with Novalis dynamic arc stereotactic radiotherapy, using an optical CT based polymer gel dosimeter. **Method and Materials:** Recent developments in mechanic accuracy of gantry and couch rotation and IGRT devices have shown that the patient setup can be corrected with sub-millimeter shift along the three vertical axes. This leads to an important question: What is the impact on the dose-volume-histogram for both target and critical organs, if the isocenter positioning error is not corrected. To assess this impact, two plastic cylinders filled with BANG® polymer gel (MGS Research, Inc) were used for dose measurements. One gel was irradiated with an adjustment on the isocenter shift due to couch rotation between couch positions. One gel was irradiated without any correction for isocenter shift. The irradiated gels were then scanned with 1 mm resolution using an optical CT scanner, OCTOPUS™ (MGS Research, Inc). Dose distributions and DVHs from two gel measurements and the treatment planning calculation were compared. **Results:** Comparison of dose distributions between the gel measurement and the treatment planning calculation showed that the agreement was within 2% in dose or 2 mm in distance. The DVH obtained from the gel measurement without any correction for isocenter shift showed smaller dose coverage at the target volume and a larger volume at the low dose (50%-80% isodose). **Conclusion:** Polymer gel dosimeter can provide a method of acquiring 3-D dose distribution for a complex treatment modality. The clinical impact of sub-millimeter error in isocenter positioning depends on disease site, target size, and other clinical information. **Conflict of Interest:** Research sponsored by MGS Research, Inc.

SU-FF-T-04

3D Intensity Modulated Proton Therapy with Minimal Beam Number

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Purpose: We investigate the influence of beam number on the quality of intensity modulated proton therapy (IMPT) treatment planning with 3-dimension (3D) modulation. Getting a good quality IMPT plan with the least beam number is critical to reduce delivery time. We seek the minimal beam number required to meet the treatment plan criteria. **Method and Materials:** An IMPT treatment-planning study was run employing an in-house treatment planning system that applied a density-scaled finite proton pencil beam dose model. The dose model ray traced to every voxel in each beamlet with an isotropic 2.5 mm voxel grid (Shannon-Nyquist limited). A 3D fluence modulation algorithm was employed using 1 x 1 cm2 beamlets with mono-energetic ranges having 2.5 mm steps between Bragg peaks along the range of the beamlet where it intersects the targets. Plans where run for 23 head and neck cases with 1 to 4 manually placed beams. The beams angles were selected to avoid critical structures if possible. We started with 4 beams then decreased the beam number while manually adjusting the beam angles for each case until we were unable to meet the planning criteria. Plans were compared with 7 beam 6 MV photon IMRT plans. **Results:** Out of 23 cases: 1 beam was sufficient for 3 cases, 2 beams were sufficient for 12 cases, 3 beams were required for 6 cases, and the 2 most difficult cases needed 4 beams. Plan quality for IMPT and IMRT were comparable with IMPT having less dose to normal tissues. **Conclusion:** The beam number required for an IMPT plan with 3D modulation can be reduced to a small number by using manual beam angle adjustment. This result indicates that beam angle optimization should be very valuable for IMPT. This work was supported in part by Florida DOH Grant 04-NIR03

SU-FF-T-05

A Biological Model-Based 4-D Lung IMRT Plan Optimization Algorithm

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Purpose: To spare the normal lung we developed a novel lung IMRT plan optimization algorithm that incorporates both biological model and respiratory motion. **Method and Materials:** We implemented a novel IMRT optimization algorithm on an in-house IMRT planning system that interfaces with an Eclipse® workstation (Varian, Palo Alto, CA). The IMRT objective function is a combination of the normal lung tissue complication probability (NTCP), the equivalent uniform dose (EUD), and a penalty on tumor dose in-homogeneity. A series of 4-D CT scans were taken at different breath phases and a deformable registration was applied to trace voxel-to-voxel correspondence at each snapshot. The time averaged (4-D) dose was utilized to calculate the NTCP and EUD in the optimization process. The proposed method was compared with the gated IMRT approach, which allowed a residual respiratory motion of 3mm and used a PTV defined as the union of the tumors at different phases within the gating window. The performance of the two approaches was evaluated via comparison of DVH at the exhale phase of the breathing cycle and quantitative parameters such as V_{20}, V_{10}, and the mean lung dose. **Results:** Five-field 6MV IMRT beams were setup to deliver a total dose of 63Gy in 35 fractions. Each plan was renormalized such that the prescribed dose covers 95% of the tumor volume. Comparing with the gated IMRT plan, our proposed method resulted in a reduction of 4.3%, 4.4%, 2.2Gy and 11.2%, in terms of V_{10}, V_{20}, the mean dose and NTCP, respectively. Meanwhile, the EUD obtained by our method was 65.6Gy, slightly higher than 64.5Gy obtained by the gated IMRT approach. **Conclusion:** Compared with the gated lung IMRT approach, the proposed biological model-based 4-D lung IMRT plan optimization algorithm is able to further spare the healthy lung tissue while maintaining relatively homogeneous tumor coverage.

SU-FF-T-06

A Biomedical Patient Data Driven Approach for the Prediction of Tumor

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Purpose: IGRT is a recent advancement in the treatment of cancer that presents a great potential to increase the efficiency of treatment of tumor in the lower abdomen and lungs. However, the efficacy of treating tumors with radiation in these locations is often degraded by tumor respiratory motion. Therefore, the characterization and prediction of tumor motion aids in the precision of radiotherapy treatment. We hereby propose a knowledge discovery solution based on the correlation of the patient biomedical data and the tumor motion data for accurate tumor motion characterization and prediction. **Method and Materials:** For the analysis of biomedical data, we worked through the main steps involved in a typical knowledge discovery analysis. An important phase includes the analysis of a large spectrum of biomedical data falling into several categories such as tumor description data, and patient treatment data in order to select the set of features to be considered for the mining process. We used clustering techniques such as K-means clustering to group patients based on a selected set of biomedical data attributes. **Results:** Comprehensive preprocessing of the raw clinical data and several experiments were performed to identify stable patient clustering. The clustering results were graphically represented using the tumor location of patients for further analysis, which clearly demonstrate certain consistency among the grouping of patients based on their biomedical information. We have compared our clustering results with the current tumor location representation based on bronchopulmonary segments. **Conclusion:** Patient biomedical data is a rich set of information that has the great potential in tumor characterization and predication especially for the treatment of patients with little or no tumor motion data. Combining the biomedical information and tumor motion data to explore the correlation among them will yield more accurate tumor motion predication. **Conflict of Interest:**

SU-FF-T-07

A Comparison Between Intensity Modulated Arc Therapy (IMAT) and Tomotherapy

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Purpose: Intensity Modulated Arc Therapy (IMAT) has been proposed as an alternative to helical tomotherapy. IMAT can be delivered on a conventional linear accelerator and uses overlapping arcs to deliver a modulated intensity pattern from each beam direction. In this study, IMAT treatment plans were developed for ten patients previously treated with helical tomotherapy. The goal was to determine if IMAT could match the dosimetric capabilities of tomotherapy. **Method and Materials:** The IMAT planning process begins with an IMRT optimization performed using the Pinnacle[3] planning system. In Pinnacle[3], beams are placed at 10° increments along each arc path. After the optimization, an arc-sequencing algorithm is applied to the optimized fluence maps to create a deliverable IMAT plan. The treatment sites in this study included lung, prostate, pancreas, brain, and head-and-neck. The IMAT plans were created under the assumption that the dose rate can vary from one beam angle to the next in each IMAT arc. **Results:** For coplanar delivery, the plan comparisons reveal that IMAT can generally provide equivalent plan quality as compared with tomotherapy. An average of 5 arcs and 692 MUs were used for these cases. In some cases improved critical structure sparing was observed in the IMAT plans at the expense of target dose uniformity. For three cases, noncoplanar IMAT plans were developed. The results demonstrate that for select cases the ability to incorporate noncoplanar arcs serves as a distinct advantage for IMAT. For example, in one case IMAT reduced the brainstem mean dose from 1866 to 606 cGy and the mean dose to the optic nerve from 388 to 95 cGy. **Conclusion:** When only axial coplaner arcs are used, IMAT plan can achieve as conformal dose distributions as tomotherapy plan. The IMAT plan, however, can provide a much better sparing to critical structures with non-coplaner arcs.

SU-FF-T-08

A Comparison Between the New Stereotactic-Mode 6 MV Beam and the Standard 6 MV Beam of Varian Trilogy Accelerators

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Purpose: Recently, a new high dose-rate radiation beam has been offered by Varian to reduce radiosurgery treatment times. The stereotactic-mode 6 MV beam (SRS-6X) operates at a dose rate of 1000 MU/min. To achieve this dose rate, the flattening filter of the standard 6 MV beam (STD-6X) was redesigned to be significantly thinner. Comparisons between the SRS-6X and STD-6X beams has been performed. **Method and Materials:** Profiles and Percentage Depth Doses (PDDs) were measured for a 3×3, 10×10, and 15×15 cm (maximum) field size. The profiles were acquired at depths: 1.6, 10 and 20 cm. Total Scatter Factors (Scp) were measured for various field sizes. All measurements were repeated for the SRS-6X and STD-6X beams on three Varian linacs. The PDD and Scp measurements were averaged over the linacs. The profile data was not averaged. **Results:** At a given depth, SRS-6X PDD curves exhibit a greater slope then that of STD-6X PDD curves. The depth 20 cm to 10 cm ionization ratio of the SRS-6X beam was 1.0% ±0.4% lower than that of the STD-6X beam. These results show that the SRS-6X beam has a lower mean energy. Excluding the tail region, the 1.6 cm depth profiles agreed to within 0.8% or 0.4 mm or better for all field sizes and the 15×15 cm profiles agreed to within 1.4% or 0.2 mm at each depth. In the tail region, the SRS-6X profiles exhibited a higher dose, indicating that the SRS-6X beam has a larger component of scattered radiation. The SRS-6X beam Scp values were 1% to 2% larger than those of the STD-6X beam. The difference increased with decreasing field size. **Conclusion:** Clinically significant differences exist between the Trilogy SRS-6X and STD-6X beams. The beam data should not be interchanged. **Conflict of Interest:** Research sponsored by Varian.

SU-FF-T-09

A Comparison of MatriXX, MapCHECK and Film for IMRT QA: Limitations of 2D Electronic Systems

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Purpose: Evaluation and comparison of 2D electronic systems versus film/ion chamber based dosimetry for IMRT QA using MapCHECK and

MatriXX. **Method and Materials:** All IMRT plans were generated with Eclipse/Helios 7.3.10 treatment planning software (Varian). Treatments were delivered on a Varian 21EX linear accelerator (6MV) with 120 leaf Millenium MLC for delivery of sliding window IMRT. The film measurements were first compared to the Eclipse dose plane. Secondly, the electronic measurements were compared to the Eclipse dose plane. Thirdly, the film measurements were compared to the electronic measurements. The film, Eclipse dose plane and MatriXX (Scanditronix) were analyzed using the OmniPro IMRT software (Scanditronix). The film, Eclipse dose plane and MapCHECK (SunNuclear) were analyzed using the MapCHECK software. Analysis was based on distance to agreement (DTA), Gamma, profile comparisons, measured dose (relative/absolute) and visual comparison. **Results:** Film and ion chamber comparisons were in good agreement as well as comparisons between electronic and ion chamber measurements. However, in some instances, electronic system measurements did not agree with film due to MLC leaf failure. Advantages and disadvantages of MatriXX and MapCheck for IMRT QA as well as specific MLC leaf failure instances will be discussed further. **Conclusion:** With many clinics implementing electronic IMRT QA devices, a careful understanding of the limitations of the MLC system and the electronic IMRT QA device is needed. We are investigating the resolution capabilities of each QA system. The MLC failure was caught before treatment began. A major disadvantage in implementing 2D electronic systems for IMRT QA is the limited resolution, resulting in limited sensitivity to MLC failures. Primary advantages of 2D electronic systems include: 1) time, 2) efficiency, 3) ease of use, and 4) overall simplification of IMRT QA.

SU-FF-T-10

A Complexity Metric for Quantitative Triage of IMRT QA

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Purpose: Our IMRT planning system can develop highly conformal plans with good dose homogeneity and avoidance of normal structures. As dose goals become more demanding the fluences which deliver the plans become more complex and the dose calculation becomes less accurate. Simple plans can be verified by a monitor unit calculation but complex cases can only be reliably confirmed by an ion chamber in phantom. An algorithm has been developed to quantitatively score the complexity of an IMRT plan, indicating to the physicist which cases can be verified with an MU calculation, which plans must be measured with an ion chamber, and where in the plan they should be measured. **Method and Materials:** Fluence patterns for each IMRT field are exported from the planning system. A complexity score, based on intensity gradient in the direction of leaf motion, is developed for each leaf pair in the plan. The calculation has been run on a number of test cases to examine the correlation between complexity score and accuracy of the dose calculation. Among the cases evaluated are several prostate plans with very little modulation, head and neck plans, and a phantom case that was manufactured to exhibit regions of high and low complexity. **Results:** All of the prostate plans, measured to better than 1% dose accuracy, had complexity scores below 100. In the simple region of the phantom plan the dose calculation agreed to with 2% of measurement and the complexity score ranged from 10 to 30. In the complex region of this plan the measured dose was 12% low and the complexity score ranged from 200 to 450. **Conclusion:** An algorithm has been developed which will allow us to direct the majority of our QA time towards difficult plans and confidently verify simple plans with an MU calculation.

SU-FF-T-12

A Critical Review of the Performance of Varian''s New Anisotropic Analytical Algorithm (AAA) Utilized in Photon Treatment Planning

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Purpose: To critically review the performance of the Anisotropic Analytical Algorithm with respect to accuracy across a complete range of 3D and IMRT treatment fields and its ability to account for tissue heterogeneities, hard and dynamic wedges, multileaf collimated beams and dynamic leaf motions. **Method and Materials:** AAA generated monitor units are compared with predicted monitor units generated by measurements at central axis in a water phantom for open fields, hard and dynamic wedges and multileaf collimated fields. AAA predicted doses are compared against measured doses in a anthropomorphic chest phantom in a complex arrangement of beams for both 6 and 18 MV photons, multileaf collimated beams and dynamic wedges. AAA predicted isodose curves are compared by digital subtraction against film recorded isodose curves. **Results:** For 6 and 18 MV photons open field beams had an average error of 0.01 and 0.00% and a maximum error of 1.17 and 1.24%; hard wedged fields had an average error of 0.12 and 0.53% and a maximum error of 1.16 and 2.32%; dynamic wedges had an average error of 1.28 and 1.87 and a maximum error of 3.3 and 4.8% respectively. These measurements had a measurement error of $\pm$1%. In the chest phantom measurements the dose was evaluated for 1) Isocenter dose, 2) Off-axis dose, and 3) Out-of-field dose. The results showed for 6 and 18 MV the average error was 1) 2.3%, 0.4%, 2) 0.7%, 4.4% and 3) 0.2%, 0.3% respectively. The digital subtraction analysis showed similar results and is displayed and analyzed. **Conclusion:** The AAA algorithm is a robust and accurate calculation engine. It shows consistent accuracy throughout the useful range of field sizes and depths. It demonstrates an improved accuracy with hard wedge beam hardening and tissue heterogeneities and successfully manages electron contamination above 5 cm in depth.

SU-FF-T-13

A Fast Scan-Plan-Treat Mode for Topographic Breast Treatment Delivery

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Purpose: To develop a fast scan-plan-treat mode that can deliver breast treatments within 15 minutes **Method and Materials:** With the advent of on-line CT imaging capability, it becomes increasingly feasible to use a radiation therapy system as a single-source device to image, plan, and deliver a patient treatment, in as little as 10-20 minutes from patient entry to exit. Such a mode can be particularly useful for cord compressions and emergency treatments. This concept is here expanded to deliver breast treatments using topotherapy, or a radiation therapy treatment delivered with concurrent couch motion but with a fixed gantry angle. MLC modulation may accompany this motion. The goal of this work was to explore: Whether auto-contouring could be used to define breast and sensitive structures. Whether this process could be completed in 10-20 minutes. The adequacy of the plans given the time constraints on both optimization and delivery **Results:** It was determined that auto-contouring could successfully contour the ipsilateral breast, the contralateral breast, each lung, and the trachea in less than 1 minute. Planning could be completed in less than 5 minutes through use of an optimization template, along with less than 5 minutes for imaging, and less than 5 minutes for delivery of 2 topographic angles. The plan optimized in this manner treated the target breast with a homogeneity of +/- 5%, and sensitive structure sparing equivalent to a conventional breast plan. Subsequent fractions can be currently created with this tool, or treated with alternate off-line optimizations. **Conclusion:** The scan-plan-treat paradigm can be combined with a topotherapy-style delivery to enable breast treatments in less than 20 minutes from the time a patient first enters the clinic. This work was supported by TomoTherapy Inc.

SU-FF-T-14

A Filmless Verification of the Radiation Isocenter for a Micromultileaf-Based Radiosurgery System

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Purpose: To assess the feasibility of a commercial electronic portal image device (EPID) along with an in-house developed software, in order to verify the alignment of the radiation isocenter. **Method and Materials:** The system used for the radiosurgery delivery consists of a Varian Clinac 2100C/D (Varian Inc, Palo Alto, CA) modified by an attachable micromultileaf collimator (m3, BrainLAB AG, Heimstetten, Germany) and equipped with a Varian Mark II EPID. A 5mm diameter tungsten ball centered in the room laser isocenter is shot and imaged with the EPID for several gantry, collimator and couch angles combinations by a 30x30mm field size shaped with m3. The software Rodeo1.1 (written using Fortran) detects the centers of the radiation field and the ball shadow in every 2D image taken. From several projections, the 3D position of the radiation

isocenter can be obtained and compared with the laser isocenter The distance between them is a measure of the alignment error which includes also the effects due to possible displacement of the portal itself that could depend on the gantry value. The accuracy of the procedure described was investigated by applying known shifts to the ball and recording the displacements detected by the mentioned software. For comparison purpose with the standard procedure which uses film and analysis by visual inspection, several pointer images were acquired and the reproducibility of two methods was stated. **Results:** The verification system composed of the EPID and Rodeo 1.1 shows an accuracy better than 0.2mm. Differences inter-observer up to 0.3mm were found when we compared the results of the film test against a perfect reproducibility with the EPID-based method. **Conclusions:** The EPID and Rodeo 1.1 set is a reliable tool for isocenter verification, with not observer dependence and time saving in relation to the film procedure.

SU-FF-T-16

A Genetic-Stochastic Approach to Volumetric Dose Optimization for Image-Based Brachytherapy: Application to Breast Balloon Brachytherapy

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We developed a stochastic algorithm to optimize volumetric dose distributions for image-based brachytherapy. The algorithm was applied for breast balloon brachytherapy of a stepping ^{192}Ir-HDR source. The weights of dwell positions in a balloon catheter define a configuration space. The algorithm consists of (1) determining a pre-optimal domain of the configuration space by a genetic algorithm and (2) searching an optimal configuration in the pre-optimal domain by a stochastic method. A configuration space was divided into five sub-domains, and each of sub-domains was further divided into the same number of weight groups. The genetic algorithm evaluated the weight sets (gene) constructed by the above discretization. A pre-optimal domain (promising gene pull) was determined by ranking the values of objective functions. Random weight sets were stochastically generated within the pre-optimal domain, having intensities uniform in a sub-domain but proportional to the density of promising weight sets. Likewise, the stochastic method evaluated the random weight sets in the pre-optimal domain. Finally, an optimal configuration is determined in terms of the number of dwell positions and weight distribution. The objective functions were to minimize the number of PTV-voxels having more than a given percent difference from the prescription dose (uniformity index), and to minimize the average difference between PTV-doses and the prescription dose (dose index). The PTV coverage can be improved by multiple dwell positions with optimized dwell weights. The optimized PTV coverage can reach above 95%. Such an enhancement is even more significant in axially elongated ellipsoidal balloons than in spherical balloons. Since the optimization shapes ellipsoidal isodoses along the catheter, it spares the part of skin by a few %. The results support the use of the genetic-stochastic algorithm for treatment planning of imaged-based brachytherapy.

SU-FF-T-17

A Graphical User Interface for a Superficial X-Ray Treatment Time Calculator

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Purpose: A new superficial treatment time calculator program was devised to provide a convenient platform for the radiation staff in superficial x-ray radiotherapy. This program has the following features: (1) Graphical user interface (GUI) to provide a user-friendly front-end window to the user; (2) A flexible, password-protected database; (3) An irregular cutout calculator to calculate the Peak Scattering Factor (PSF) of an irregular field; (4) Simplified import of the irregular field image to the calculator; and (5) Patient treatment record printing as an electronic file or hardcopy. **Method and Materials:** The calculator program was written using Microsoft Visual Basic.net framework and adapted to the Gulmay D3150 superficial x-ray unit. Dosimetric information such as PSF and OF tables were needed for each treatment energy. They were measured and input to the database. The predicted and measured dose in the commissioning should be smaller than ± 2%. **Results:** The GUI and "HELP" menu made the user easier to calculate the treatment time compared to using forms and tables. It also reduced training time and human error. Physicist can setup, input and delete treatment beam in the database, which is password protected. For the irregular lead cutout, an irregular field calculator routine is associated with the software to determine the PSF using sector-integration algorithm. The user only needs to prepare a JPEG file of the irregular field printout using a scanner and import such graphic file to the calculator to determine the PSF.**Conclusion:** A treatment time calculator program using GUI technique was made in the Grand River Hospital. Such a program aims at providing a convenient way for the user to calculate the treatment time and keep a record. It is concluded that such calculator can reduce the man-hours and increase the efficiency in the superficial x-ray treatment.

SU-FF-T-20

A Method for Evaluation of the Dose Prediction and Optimization Convergence Errors

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Purpose: IMRT optimization solutions are influenced by the computation algorithms used in the estimation of the radiation field incident upon the patient as well as the dose calculation algorithm. This work describes a technique for evaluating the dose prediction errors (DPEs) and optimization convergence errors (OCEs) due to inaccuracies in the heterogeneity correction of the optimization dose calculation algorithm. **Method and Materials:** The heterogeneity-induced DPE and OCE of convolution-based optimization are studied by utilizing a sequential deliverable-based IMRT optimization. Initially, a method (Mx^{Opt}) utilizing a Monte Carlo (MC)-based algorithm to estimate the incident upon a patient fluence (derived from the MLC leaf sequences), coupled to a conventional (convolution) dose calculation algorithm, is used for the optimization. Following the Mx^{Opt} optimization convergence, a second method which utilizes MC for both fluence prediction and dose deposition in a patient is performed. DPEs due to patient heterogeneities and incident fluence prediction are evaluated by re-computing Mx^{Opt} converged solution with a full MC (Mx^{Opt}+MC) method, while OCEs are evaluated by comparing the Mx^{Opt}+MC computed dose with the converged MC^{Opt} optimization result. The technique is evaluated by performing the optimization sequences on two Head-and-Neck IMRT patient plans. Dose-volume indices were evaluated to compare the plans. **Results:** For the plans assessed, the GTV D_{98} and CTV D_{95} indices agree within ±2% for both DPE and OCE estimations. The Nodal-CTV D_{90} DPEs and OCEs are within 3%. The DPEs and OCEs in the critical structures (Cord D_{02}, Brainstem D_{02}, and Parotid D_{50}.) are less than 3.5%. When MC^{Opt} follows Mx^{Opt}, only 3-4 iterations were required for convergence. **Conclusion:** A technique for evaluation of the DPEs and the OCEs in the deliverable IMRT optimization has been developed. The feasibility of the proposed technique was demonstrated on two Head-and-Neck deliverable IMRT plans. (Supported by NIH-1R01CA98524)

SU-FF-T-21

A Method to Increase the Resolution of IMRT Plan Verification with a Two-Dimensional Ionisation Chamber Array

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Purpose: We have developed a method for high resolution dosimetric plan verification with two-dimensional ionization chamber arrays. **Methods and Materials:** The used 2D-Array (PTW Freiburg, Germany) contains a matrix of 27 x 27 ionization chambers, each with an entrance window of 5 mm x 5 mm and with 5 mm wide ridges between the chambers. For an IMRT plan verification, the calculated dose distribution of the patient is exported to a CT of a phantom containing the 2D-Array. The finite size of the chambers is accounted for by convolving the calculated dose distribution with the lateral transfer function of a single chamber. Considering the Nyquist theorem the chamber-to-chamber distance of 10 mm permits to resolve spatial frequencies up to 0,5/cm. **Results:** The resolution of the system can be doubled to 1,0/cm by shifting the array 5 mm in both x and y-direction and repeating the measurement. By this the chambers will be positioned where the ridges have been in the first measurement. In most IMRT sequences the sizes of field elements are usually not smaller than 1 cm x 1cm, therefore the verification of these

techniques can be achieved with sufficient resolution. Since lateral dose gradients are much higher in segmental than in dynamic IMRT techniques, the sampling distance may be increased for the latter. **Conclusion:** As most planning systems offer the possibility of limiting the field size to areas larger then 1 cm x 1 cm, a single measurement will mostly be sufficient for the verification. Clinical examples show the wide and easy applicability of the described methods. **Conflict of Interest:** The method was developed in cooperation with PTW-Freiburg, Germany.

SU-FF-T-22

A Method to Reduce the Dose Uncertainty Caused by High Energy Cutoffs for Monte Carlo Treatment Planning

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Purpose: A method to reduce the statistical uncertainty of dose caused by high energy cutoffs for electron transport was implemented in our home-grown Monte Carlo treatment planning system. **Method and Materials:** In Monte Carlo radiation transport, an electron is discarded and its energy is deposited locally when its total energy is below a cutoff energy. The deposited energy is significantly higher than that calculated using the CSDA model with the corresponding restricted stopping powers. This will create a higher statistical uncertainty on dose and generate a confusing dose distribution, especially when low-density voxel exists. In this work, a new technique was developed by continuously transporting a discarded electron without considering electron multiple scattering or secondary particle generation. It has a continuous energy loss based on its mass collision stopping power in the local medium with an additional energy loss (about 70%) to account for the effect of approximations made in transporting the electron in a straight line rather than a curved path. **Results:** After the new method was applied, the statistical uncertainties of the doses in air cavities of a head-and-neck patient was reduced from up to 39% to the same level of that in the surrounding tissue which is only about 2%. The dose statistical uncertainties of the tissue voxels were also reduced by 9% of their initial values. The simulation time with the new method was increased by 9%. And thus, the simulation efficiency was increased by 9% when the energy cutoff is 0.7MeV. When a cutoff of 1.5MeV was used, the new method increased the simulation efficiency by a factor of 3. **Conclusion:** A new technique was developed to reduce the statistical uncertainty of doses in low-density voxels caused by high energy cutoffs for electron transport. The calculation efficiency and the dose distributions were improved significantly.

SU-FF-T-23

A Mixed Integer Formulation for Direct Aperture Optimization of IMRT

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Purpose: Direct aperture optimization (DAO) has the potential to simplify and therefore accelerate IMRT delivery. However, the algorithmic side of DAO is challenging. The commonly used simulated annealing algorithm is slow. Moreover, it is not guaranteed to find the best solution. This motivated us to investigate the feasibility and utility of mixed integer programming (MIP) in DAO." **Method and Materials:** We consider an objective function which is linear in dose. For the dose calculation, we apply a dose matrix concept. The dose D_q in a voxel q is given by $D_q=\sum_n\sum_j w_{nj}d_q^{nj}$, where w_{nj} is the fluence weight for beamlet j in aperture n and d_q^{nj} is the precalculated dose contribution of this beamlet to voxel q for unit fluence. In order to form valid apertures, two types of conditions have to be imposed on the beamlet weights. First, beamlet weights w_{nj} which belong to the same aperture have to be either zero or equal to a common aperture weight. Second, non-zero beamlet weights which belong to the same leaf pair must be connected, i.e. if two beamlet weights in one row are non-zero, the weights in between have to be non-zero aswell. Both conditions can be formulated in terms of linear constraints if a binary variable for each beamlet is introduced. **Results:** The formulation has been tested for the RTOG benchmark phantom which mimics a paraspinal case using the commercial software CPLEX. The mixed integer program could not be solved to optimality, however, integer solutions were obtained within a reasonable computation time. **Conclusion:** The mixed integer formulation for DAO was applied successfully to an idealized phantom geometry. Current research considers the applicability to large size clinical cases.

SU-FF-T-24

A Model for Handling Infeasibility Arising From IMRT Inverse Planning

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Purpose: IMRT has been widely adopted to create conformal dose distributions. This technology is particularly useful in situations where critical structures push against the target or targets to create a concavity in the PTVs. It is difficult to develop a set of dose constraints that will work in all cases, and current IMRT inverse planning has become an iterative process that involves manual adjustment of various objectives. We investigate a new approach that allows the dose constraints to be varied (relaxed) in an organized way within the optimization process so that feasible solutions can be found for an originally infeasible problem. **Method and Materials:** The IMRT inverse problem can be formulated as a system of linear inequalities with the dose upper/lower limit. For each of the targets or critical structures, the upper and lower limit can be relaxed to allowed up to α% of the volume to have the dose limit decreased or increased up to β%, respectively. Linear inequalities of a heuristic nature are formulated for these dose and volume relaxations. When infeasibility is encountered, each of the α and β are dynamically incremented by $\Delta\alpha$ and $\Delta\beta$. Iteractions are stopped when pre-defined α_{max} and β_{max} values are reached. These inequalities are solved using a linear programming method. Multiple feasible α and β pairs are returned when their limits are chosen forgivingly. **Results:** Over 200 test cases of various sizes are randomly generated in a controlled manner. All experiments reached acceptable relaxed solutions. Successful relaxations are also found for a clinical IMRT case with multiple α and β pairs. **Conclusion:** This approach can be an advantage for busy dosimetrists and clinicians that might otherwise be challenged by the prospect of generating multiple alternate plans. The approach described will produce a series of plans with relaxed constraints when the original dose limits are not met.

SU-FF-T-25

A Modified Azakawa Technique for Total Scalp and Neck Irradiation Utilizing a Custom Wax Bolus

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Purpose: To develop a durable custom bolus helmet for Total Scalp and Neck Irradiation and to quantify the dosimetric aspects using a Modified Azakawa Technique for treatment delivery. **Method and Materials:** A custom bolus helmet for total scalp and neck treatment was fabricated from dental wax overlaid on a dual exoskeleton of Med Tech™ face mask mesh that conformed to the patients head. With helmet on, the patient was immobilized with a conventional facemask. Following CT simulation, treatment planning was performed in ADAC™ Pinnacle 3 planning system in heterogeneous mode for the combined photon and electron treatment fields. Opposed photons fields (6x) treat the sagital scalp and posterior neck; lateral scalps are treated with enface electrons that overlap the photon fields by 3-4 mm. Lateral necks were treated with en face electron fields that abutted the electron scalp fields. Beam central axes were kept coincident to provide ease of setup for the 6 customized ports. After half of the dose was delivered all field junctions were “feathered” by altering the junction locations by about 1 cm. A diode with 2mm build-up was calibrated as a point detector to validate the dosimetry at multiple patient points. Results: Compared to the maximum dose of the prescription, the measured doses typically ranged from –5% to +15%; a single point yielded +20% at a photon and electron junction. **Conclusion:** The wax helmet proved to be extremely durable for more than 30 fractions. Additionally, the helmet provided “instant bolus” easily accommodated by the patient, appreciated by the RTT staff, and aided in reproducible dosimetry for this challenging treatment site.

SU-FF-T-26

A Modified TG-51 Formalism for Gamma Knife Dose Rate Calibration

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Purpose: The first Lekshell Gamma Knife was developed in 1968. Currently there is no national standard calibration protocol developed specifically for gamma knife dose calibration. Many gamma knife centers perform calibration using TG-21 protocol, while other centers use TG-51 calibration factor $N_{D,W}$. The purpose of this study is: to exam TG-21 and TG-51 calibration formalism; to compare result of gamma knife dose calibration using these two methods; and to determine if a simplified formula can be applied to gamma knife dose rate calibration. **Method and Materials:** Exradin A16 ion chamber (wall material C552) was placed in a 16cm spherical polystyrene phantom in our Lekshell Gamma Knife 4C. Dose rate can be calculated using Ngas or $N_{D,W}$:

TG-21 $D_{Water}/M = Ngas \times (L/\rho)^{med}_{air} \times P_{wall} \times P_{repl} \times (\mu/\rho)^{med}_{water}$

"Modified TG-51" $D_{Water}/M = N_{D,W} \times k$

where M is corrected charge reading; k an unknown correction for polystyrene phantom.

Left hand side of the equations is dose rate to water per unit charge. For a given chamber, the factors on the right side of equations are all known except k, which can be determined by comparing above equations. **Results:** For our A16 chamber:

$N_{D,W} / Ngas = 1.101$

$(L/\rho)^{med}_{air} \times P_{wall} \times P_{repl} \times (\mu/\rho)^{med}_{water} = 1.122$

Even if we ignore the unknown correction factor k, the difference between TG-21 and TG-51 calculated dose rate is 1.9%. Thus we estimated k to be in the order of 2% for this A16 ion chamber. **Conclusion:** A "modified TG-51" formula, $D_{Water} = M \times N_{D,W} \times k$, can be used to calibrate gamma knife dose rate. Correction factor k can be determined from the values of $N_{D,W}$, Ngas, and other known factors found in TG-21. Difference between "modified TG-51" and TG-21 calculated dose rate is expected to be less than 2%.

SU-FF-T-27

A Monte Carlo Based Tumor Model

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Purpose: To develop a stochastic, radiobiological tumor model to conduct *in silico* simulations of cell proliferation and to quantitatively assess biological effects of delivered dose and different irradiation regimes. **Method and Materials:** We developed a Monte Carlo model to perform computer simulations on initial tumor growth, progression of predetermined cell distributions and cellular response to irradiation following the linear-quadratic model. The single-cell-based configuration is composed of a volumetric grid lattice, with each grid site representing a capillary, clonogenic or normal tissue cell. Mean values for biological parameters such as cell cycle time and cell cycle phase dependent radiosensitivity were adopted from literature and sampled restrictively from Gaussian distributions for each cell. Additionally, angiogenesis, apoptosis and necrosis were implemented and random processes like cell displacement after proliferation and radiation-induced DNA damages were modeled using probability density functions. **Results:** Simulations of initial tumor formation and ongoing proliferation illustrate a decelerated growth rate with increasing cell cycle times and hypoxia occurrence, whereas low thresholds for capillary stimulation through tumor angiogenesis factors lead to accelerated proliferation. Analyses of tumor response to different fractionation patterns show faster and stronger expression of necrosis after accelerated time-dose-patterns. A benchmark against published experimental data with human HNSCC-6 tumor cell lines demonstrates good quantitative agreement. **Conclusions:** Our model is able to qualitatively predict basic radiobiological behavior and implicitly includes the 'four Rs of radiotherapy' as a result of the cellular approach. In order to apply the model to a specific tumor, it has to be tuned by including *in vivo* data and benchmarked against experiments. Given the adequate biological input parameters, good quantitative agreement can be achieved. This model could be enhanced to help predicting treatment response and bring us one step closer to biological optimization models.

SU-FF-T-28

A Monte Carlo Study On Carbon RBE for Carbon Therapy

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Purpose: To estimate carbon RBE for radiotherapy planning based on a RBE-LET model using Monte Carlo (MC) simulations. **Method and Materials:** The MC method has been implemented for carbon (C^{6+}) dose calculations for radiation therapy treatment planning. The FLUKA code is used to generate carbon ion tracks in medium and incorporate them into MCDOSE for patient dose calculation. A two-step optimization scheme is used to yield 3-D conformal and homogeneous dose distributions. First, we select the small carbon beams (beamlets) with proper energy spectra to generate SOBPs based on Boltzmann transport equation. Those beamlets with SOBPs can be used for conventional particle therapy (CPT) and can be further used for intensity-modulated particle therapy (IMPT). We have either used a constant RBE (=5) or a variable RBE in the beamlet dose calculation. RBE is calculated based on the RBE-LET model:

$$\mathrm{RBE}(D, L, \alpha_0, \lambda, \alpha, \beta) = \frac{\sqrt{\alpha^2 + 4\beta D(\alpha_0 + \lambda L + \beta D)} - \alpha}{2\beta D}$$

where $\alpha_0, \lambda, \alpha, \beta$ are determined by experiments. L is energy linear transfer (LET) that can be calculated by the Bethe-Bloch formula:

$$L = -\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\left(\frac{2m_e\gamma^2\beta^2 W_{max}}{I^2}\right) - 2\beta^2\right] \quad .$$

Results: Ten prostate treatment plans were generated using carbon beams for this study. The target dose was prescribed to 76 Gy (Co-equivalent), and 7-9 beams were used for all the plans. Comparisons were made between carbon CPT and carbon IMPT with a constant RBE and variable RBE. The ratio of mean doses with a constant RBE and with variable RBE varied depending on the plan and the organ. Generally, for CPT plans, the ratio was 1.06 for the target dose, 1.26 for the bladder, and 1.3 for the rectum. Through optimization, these differences were reduced for IMPT plans; the ratio for the target was about 1.0, 1.11 for the bladder and 1.03 for the rectum after RBE-corrected optimization. **Conclusion:** The RBE-based optimization is needed to correct the RBE effect for optimal target coverage and critical structure sparing in IMPT treatment planning.

SU-FF-T-30

A Nested Partitions Framework for Beam Angle and Dose Optimization in IMRT

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Purpose: To present a novel algorithm, nested partitions (NP), capable of finding suitable beam angle samples for IMRT treatment planning by guiding the dose optimization process. Beam angle optimization and dose optimization are two problems which are conventionally solved separately, because coupling the variables increases the size and complexity of the combinatorial optimization problem. **Method and Materials:** NP is a metaheuristic algorithm, guiding the search of a deterministic dose optimization algorithm. The NP method adaptively samples from the entire feasible region, or search space, and concentrates the sampling effort by systematically partitioning the feasible region at successive iterations. We used a "warm-start" approach by initiating the NP with beam angle samples derived from an integer programming (IP) model. We implemented the NP framework in conjunction with a quasi-newton dose-optimization algorithm employed in a commercial treatment planning system. We evaluated the results using 7-field plans for two test clinical cases: head and neck and pancreas. **Results:** The results of four iterations of the NP algorithm outperformed both the initial IP solution and a generic equi-spaced beam angle plan. This evaluation was based on DVH constraints for the critical structures for both clinical cases. For example, in the head and neck case, the NP plan delivered a dose of greater than 35 Gy to just 4.3% of the spinal cord, compared to 5.2% for the IP plan and 41.4% for the generic plan. In the pancreas case, the NP delivered a dose of greater than 23 Gy to 30.9% of the right kidney, compared to 43.7% (IP plan) and 49.0% (generic plan). **Conclusions:** Our results indicate that the IP solution provides a good initial solution. In addition, by employing the NP framework, further

improvement is achieved. This makes it possible to produce a high-quality solution within a reasonable amount of time.

SU-FF-T-31

A New 4D IMRT Algorithm and Its Performance Analysis

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Purpose: Current radiation treatment practice neither detects nor adapts to intrafraction organ motion beyond gating. We develop a simple optimization scheme for 4D IMRT which doesn't rely on gating and simulate its performance in the presence of the anticipated organ motion and unanticipated setup errors and tissue motion. **Method and Materials:** We wrote MATLAB code modeling treatment of a 2D phantom using the beamlet model. We also used geometry from a lung case. SNOPT (a commercial SQP optimization code) selects beamlet weights minimizing the weighted quadratic deviation from some desired dose. Suppose the beam-on time is divided into N phases and the prescription dose is D^*. For location r in phase i, let $D_i^*(r)$ be the planned dose; $D_i(r)$ the actually delivered dose; and $r=A_i(v)$ the anticipated location of voxel v. Our two baseline algorithms use static plans ($D_i^*=D_j^*$ for any phases i,j) and gating ($D_i^*=0$ for phases $i\neq 1$). In both cases we choose feasible $D_1^*+...+D_N^*$ minimizing the weighted quadratic deviation from D^*. Our 4D algorithm selects $(D_1^*,...,D_N^*) \in \arg\min_{(D1\in F,...,DN\in F)} \sum_v \alpha(v)(D1(A_1(v)) +...+DN(A_N(v)) - D^*(v))^2$

Simulation determines the delivered dose D_i from the anticipated dose D_i^* by adding noise and incorporating setup error (translation and rotation of the patient) and tissue distortion caused by unanticipated small organ motion. For our algorithm and the baseline, we compare the DVH of the cumulative dose $D_1+...+D_N$ and the margin needed to achieve a satisfactory cumulative delivered dose. **Results:** We achieved significant improvement in the objective function (delivering more dose to the tumor and less to the organ) on our test case with 3cm motions. **Conclusion:** This new paradigm of 4D IMRT holds significant promise for improving the current radiation therapy.

SU-FF-T-32

A New Dose Optimization Algorithm for Adaptive Radiation Therapy

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Purpose: Current radiation treatment plans do not adapt to errors (and other deviations from the target dose distribution) in already delivered fractions. We assume that the dose actually delivered (including any errors) is known after its delivery. We devise a dynamic control algorithm compensating for these errors by adapting the plan for the current fraction. **Method and Materials:** We wrote MATLAB code that models treatment of a 2D phantom using the beamlet model. We used SNOPT (a commercial SQP optimization code) to select beamlet weights that minimize the weighted quadratic deviation from some desired dose. We also apply our algorithm to a head and neck case. Suppose the prescription dose is D^* over N fractions; D_i^* is the dose planned for fraction i; and D_i is the dose actually delivered in fraction i. Our baseline (algorithm) chooses for fraction i the feasible plan, D_i^*, that minimizes the weighted quadratic deviation from D^*/N. Our adaptive algorithm selects for fraction k the feasible plan D_k^* that minimizes the weighted quadratic deviation from $D^*(k/N)-D_1-...-D_{k-1}$. Simulation determines the delivered dose D_i from the anticipated dose D_i^* by adding noise and incorporating setup error (translation and rotation of the patient) and tissue distortion caused by small organ motion. We compare the adaptive algorithm to the baseline and an algorithm with perfect foresight. For the algorithms, we compare the DVH of the cumulative dose $D_1+...+D_N$ and the margin needed to achieve a satisfactory cumulative delivered dose. **Results:** We achieved significant improvement in the objective function while delivering more dose to the tumor and less to the sensitive structures on our test case with setup errors of ±1cm and ±2°. **Conclusion:** This new paradigm of adaptive radiation therapy (ART) holds significant promise for us to improve the current radiation therapy.

SU-FF-T-33

A New Formula for Normal Tissue Complication (NTCP) as a Function of Equivalent Uniform Dose (EUD) in the Lyman-Kutcher-Burman (LKB) Model

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Purpose: Use of biological outcome predictions in treatment planning represents a potential improvement over purely dose-based planning. To promote increased use of outcome predictions, a mathematical tool is developed for the widely-used Lyman phenomenological model of normal tissue complication probability (NTCP). **Method and Materials:** A simpler-appearing formula that accurately approximates the Lyman model for NTCP is introduced. The new equation for NTCP as a function of the equivalent uniform dose (EUD) is similar to the LQ formula for single-fraction single-cell survival. **Results:** To within 0.2%, the Lyman formula for a uniformly irradiated OAR is given by an analytical representation similar to the LQ formula for single-fraction cell survival, with tissue parameters derived from those in the Lyman formula. The formula differs from that of the LQ model for cell kill in that the parameter corresponding to the α/β ratio is negative. Simple equations are given to calculate formula parameters from m and TD_{50} for organs at risk (OARs) in the Lyman model. Likewise, equations are given for calculating m and TD_{50} from parameters in the new formulae. The role of the volume-effect parameter n is not changed from the Lyman model, and is used to calculate EUD for non-uniformly irradiated OARs based on the Kutcher-Burman (K-B) reduction algorithm. A table of parameter values is presented derived from published Lyman parameter fits to the Emami compilation of normal tissue complications. **Conclusion:** New linear-quadratic type formulae are shown to be useful in depicting the results of the LKB model for NTCP for inhomogeneously-irradiated OARs. Transformation formulae are given for the LQ-NTCP parameters in terms of the Lyman parameters m and TD_{50}, and tables of LQ-NTCP parameters are given, based on published Lyman model fits to various OARs. An equation is given for the EUD corresponding to pre-selected levels of NTCP.

SU-FF-T-34

A New Method of Beam Let Weight and Dose Reconstruction for IMRT: Fine Mesh Study

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A new method was developed for the reconstruction of beamlet weight and dose in a patient in intensity modulated radiation therapy (IMRT). The method is based on linear relationship between beamlets and dose scoring voxels in EPID, expressed in terms of beam let weights and kernels. Thus, the reconstruction does not involve iteration or assumption of dose image in EPID as a primary fluence. The kernels quantify dose deposition in each voxel in EPID from each beamlet and are determined by Monte Carlo particle transport calculations. The method was demonstrated computationally on a coronal plane in a phantom. Kernels on this plane and EPID were first calculated for each beamlet. Two IMRT dose distributions of pyramid and inverse pyramid shapes were constructed in phantom and EPID by weighting kernels of each beam let differently. An accident or error was designed by changing the weight of a certain beamlet, modeling MLC uncertainty or output instability. Using the dose difference in EPID due to the accident, the relationship was inversely solved for the changed amount in beamlet weight. For the demonstration, 30 x 12 (6 x 6 cm^2) source matrix was used involving the construction of 1296 X 360 kernel matrix in EPID and less than 10 seconds of calculation time and 10 MB of memory were used. The dose change due to the accident in phantom was calculated weighting the predetermined dose kernels in phantom by the reconstructed weight difference. Comparing the reconstructed weight change with the imposed change, the result showed a negligible error due to rounding-off of data. This validation has shown that the method is practically suitable for the verification of IMRT and useful for application in adaptive radiation therapy. A follow-up study will be performed, that includes detailed modeling of a therapeutic beam and EPID and experiments.

SU-FF-T-35

A New Monte Carlo Treatment Planning Toolkit for Modulated Electron Radiation Therapy (MERT)

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Purpose: Investigation of Modulated Electron Radiation Therapy (MERT) in our department using Monte Carlo led to a number of codes that are interacting with each other in order to calculate the final dose distribution. In this work, we present a treatment panning toolkit (TP toolkit) that controls the data flow at each step of the procedure. **Methods and materials:** The codes involved in the MERT process are the initial beamlet calculations, beamlet optimization, dose calculation, secondary optimization, leaf sequence, etc. The major drawback of the whole MERT calculation process is that there are several steps until the final dose calculation in the patient and mistakes in the input files are common that lead to erroneous results. Furthermore, all the inputs are written in text and parameters are stated in numbers without any indication of their meaning. The TP toolkit will able the user to plan the treatment and review the results. **Results:** The TP Toolkit is written in Java that makes it operational regardless of the operating system. It consists of windows that provide common-style menus and buttons to navigate the user through the edit dialog boxes. The most important feature of the TP Toolkit is its graphical user interface (GUI) and its ability to link programs that are used for the computation and visualization of the dose distributions obtained after each step throughout the treatment planning process. The TP Toolkit can be also be used to create input files for photon beam dose calculations using EGS4/MCSIM using RTP files, intensity maps, blocks or simple rectangular fields. **Conclusions:** Since Java is a modern language, it offers advanced tools to create the TP Toolkit and to "glue" different applications to it that allow the user to plan, review and evaluate treatment plans.

SU-FF-T-36

A New Nomogram for Determining I-125 Prostate Seed Implant Activity

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Purpose: To reduce the number of seeds returned to the vendor after prostate implants by devising a new nomogram for predicting activity.
Method and Materials: During 2005, we implanted 36 patients. Pre-implant volumes were determined ultrasonically by measuring the ellipsoidal diameters. The mean pre-implant volume was 35.1 cc while the implant measurement was 38.5 cc, a difference of 9.7% which correlates with the 10% volume increase used for ordering. We plotted the volumes against the activity. These data were fitted to a linear function. The function was further modified by increasing the activity in order to accommodate all of the clinical cases. **Results:** We used the new nomogram to predict the required activity first by using the pre-implant volumes, and second by using volumes with the minimum volume being 30 cc. The former predicted an excess activity of 219.7 mCi compared to the actual excess of 279.4 mCi. The difference resulted in a savings of 145 seeds (0.413 mCi/seed). The latter produced an excess of 231 mCi; 48.8 mCi (118 seeds) less than ordered. **Conclusion:** Our study of patients implanted in 2005 resulted in the generation of a new nomogram, showing a linear relationship between volume and activity. Had we used this function and the unadjusted pre-implant volumes in 2005, we would have saved 59.7 mCi, about 145 seeds.

SU-FF-T-37

A New Plan Technique for the Bilateral Orbit Lymphoma

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Purpose: The radiotherapy for bilateral orbital lymphoma which involves retrobulbar area and lacrimal gland is challenging. We present a new 3D conformal radiotherapy technique using MLCs. **Method and Materials:** The PTVs of right and left orbit were defined on axial CT images, which are cone shaped volume with concave base surrounding lenses. The PTVs were split into anterior and posterior compartment at the posterior part of eyeball. The posterior PTVs were irradiated using bilateral 6 MV photon half beams. The anterior PTVs were irradiated using five 6 MV photon beams arranged in coronal plane with couch rotation. The couch angles were 30^{o}, 60^{o}, 90^{o}, 300^{o} and 330^{o} with gantry angle of 90^{o} or 270^{o}. Lenses were shielded appropriately with 5 mm width MLCs in each beam. **Results:** The 90% of PTV received at least 3000 cGy, the prescribed dose. The maximum dose to lens was 650 cGy. This result is comparable to previously reported 4 field technique (anterior superior/inferior and anterior left/right oblique fields with rod shaped lens block for each orbit). The IMRT trial showed acceptable dose distribution and DHVs when optimized. After conversion into deliverable ODM, however, the lens dose increased unacceptably and the PTV coverage deteriorated.
Conclusion: Our technique using MLCs achieves adequate dose coverage for PTV and spares lenses acceptably. It is superior to 4 field technique in terms of treatment delivery as it needs no specialized lens block and superior to IMRT in terms of dose distribution.

SU-FF-T-38

A New Software Tool for Plan Analysis and Comparison

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Purpose: To develop a simple software tool which allows quantitative analysis and comparison of multiple treatment plans using physical and biological parameters. **Method and Materials:** When comparing multiple IMRT and/or conventional radiotherapy plans, it is often difficult to choose the best plan by visual inspection of DVHs and associated statistics such as "hot spots" and "cold spots". Comparison of multiple rival IMRT and 3D plans can become a cumbersome process, particularly if different planning systems are used for each. To overcome these problems, we developed a Java-based software tool called MPACT (Multi-parameter Plan Analysis and Comparison Tool) to evaluate treatment plans using physical and biological parameters. MPACT directly imports patient and DVH information from the treatment planning system(s) and calculates gEUD (generalized Equivalent Uniform Dose), HI (Homogeneity Index), and CI (Conformity Index). The user may import as many plans as desired and compare these parameters for all plans on one screen. **Results:** MPACT has been used to assess the clinical advantage of breast IMRT for the first 10 patients treated at our center. While DVH analysis did not often reveal significant differences or provide an easy means for quantitative comparison, MPACT revealed that IMRT provided an 8% increase in the average target gEUD, 3% and 1% decreases in lung and heart gEUD, respectively, and a 3% increase in the average HI and CI in comparison to conventional compensator plans. **Conclusion:** MPACT provides a convenient mechanism for plan comparison for any treatment site, and facilitates an objective, quantitative decision-making process. It has proven to be a valuable tool for comparison of conventional and IMRT radiotherapy plans or multiple competing IMRT plans. The addition of TCP and NTCP calculation functionality is currently underway, and MPACT will ultimately serve as a platform for a plan optimization system using these calculated parameters.

SU-FF-T-40

A Novel Phantom for Use in 3-Dimensional in Vitro Cell Experiments

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Purpose: To describe and characterize a novel IMRT phantom for use in 3-dimensional *in vitro* cell experiments. Methods and Materials: A cylindrical IMRT phantom was designed and fabricated from a commercially available system (CIRS Inc., Norfolk, VA). The phantom is composed of water-equivalent plastic and contains a rectangular bore which, in combination with a set of water-equivalent plastic inserts, can be adjusted to fit 1-3 well plates. In these initial studies, the phantom was loaded with a stack of three well plates (96 individual wells/plate), and an IMRT plan was created for two separate PTVs, each receiving a scalable uniform dose. The ratio of doses between the PTVs was fixed at 2:1. Using PTV doses of 50 and 100 cGy, measurements from TLDs placed at five locations within each PTV were compared to the expected doses. For the same irradiation technique, dose distributions were acquired from films placed above and below each well plate and compared with the treatment plan using the γ–index. Head and neck tumor cell lines were also irradiated in this phantom and cell viability was assessed using the MTT assay. **Results:** TLD measurements yielded doses of 100.3 +/- 4.6 cGy and 51.0 +/- 2.3 cGy for 100 cGy and 50 cGy PTVs, respectively. Calculations of γ were performed using a dose difference of 3.0 mm and distance to agreement of 3.0 %. The γ indices ranged from 0.18 +/- 0.13 to 0.51 +/-

0.35 in each of the PTVs. Cell irradiation experiments showed uniform viability within each of the PTVs. **Conclusion:** The consistency between measurements obtained from the TLDs and film with the calculated dose distributions, along with uniform cell viability within each irradiation region, show that the phantom is a novel tool for 3-dimensional *in vitro* cell experiments. **Conflict of Interest:** Supported by a grant from MedImmune.

SU-FF-T-41

A Novel Tomotherapy Design for the Breast

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Purpose: Previous work on partial breast irradiation in the prone position has lead to the development of a new treatment modality made specifically for the breast. Current methods often utilize a modified two-tangent approach meaning beams are delivered around the body. This device, on the other hand, takes advantage of the unique geometry of the prone breast by rotating around it to deliver a highly targeted dose to the PTV, while sparing the normal breast tissue and other non-breast structures. This device will involve helical tomotherapy but on a rotated axis. This will allow many more angles to be utilized compared to the standard methods. **Method and Materials:** Several technical and clinical aspects of this device have been explored. The technical aspects include the design of a new target, shielding requirements, and energy fluence distributions. The clinical aspects researched include dose distribution comparisons from several different potential energies and the determination of patient selection criteria. **Results:** These investigations have shown that a 4MV x-ray beam created from a beryllium target would be the optimal design. Since the breast is a thin structure, a higher energy is not need. However if the energy is any lower, the skin dose will increase. Beryllium targets are ideal for this machine since the forward output is roughly 70% that of tungsten for field sizes up to 10 cm, but the lateral energy fluence is significantly less. **Conclusions:** This machine is able to produce brachytherapy like PBI dose distributions that consist of highly conformal doses to the target and low doses to the non-target structures. It is also able to achieve this without the additional surgery required for brachytherapy procedures. In addition, a large percentage of breast patients would be eligible for this treatment, since it is able to deliver dose close to the chestwall.

SU-FF-T-42

A Pesudo-IMRT Method for Improving the Dose Uniformity in the Spine in Cranial-Spinal Irradaition

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Purpose: To improve the dose uniformity in the treatment volume in Craniospinal Irradiation (CSI) by using a pseudo-IMRT method. **Material & Method:** A supine setup was used for both patient comfort and anesthesia administration. Opposed lateral fields with pedistal and collimator rotation were used for cranial irradiation, while PA field were used for the spine. The cranial plan was conventional. Since the standard uncompensated spine field has poor dose uniformity within the cord, a novel pseudo-IMRT method was developed. By adding 2cm to each side of the spinal canal, a structure called "cord Band" was created. Then, the beam fluence and dynamic leaf sequences were optimized to deliver a uniform dose to the "cord band". If two PA fields were used, a 4 to 6 cm region of overlap was provided. The optimization process smears out the hot and cold spots typically seen in conventional field matching, resulting in a configuration which is more forgiving of daily setup errors. **Results:** The pseudo-IMRT method shows great improvement in dose coverage in the spine compared with the conventional uncompensated PA field. The percent volume covered by 95% of the prescribed dose increased form 88.3% to 98.3%. The percent volume over 110% decreased from 12.2% to 2.1%. The hot and cold spots resulted from matching the two PA fields in the conventional treatment are significantly reduced. This method increases the maximum dose outside treatment volume; however, this region is always located posterior to the vertebral body. **Discussion:** We have developed a pseudo-IMRT treatment method for delivering a significantly improved uniform dose to the spine in the CSI. This method shows even more advantage in case two spine fields are required. The hot and cold spots are smeared out and the feathering between the two PA fields are eliminated.

SU-FF-T-43

A Planar Dose Calculation Algorithm for IMRT Quality Assurance

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Purpose: To develop a fast algorithm for independent planar dose verification of IMRT plans delivered with an MLC as part of the IMRT quality assurance procedure. **Methods and Materials:** A fast empirical IMRT planner dose calculation algorithm was implemented. In-air output factors were used to model the source distribution, which is used to calculate the planar fluence at the detector plane based on the projected source integration on the source plane shaped by the combined positions of the jaws and MLC. The planner dose is obtained by convolving the planner fluence with a kernel, which is modified from the published kernel by fitting to standard field profiles at the specified depth. MLC-introduced dosimetric effects, such as leaf transmission, rounded leaf end, and tongue-and-groove effects were accounted for explicitly by empirical fits to measured data. The algorithm was applied to two linac models with completely different head designs: a Varian 2100 C/D with 120-leaf MLC and an Elekta Synergy S with Beam Modulator (40-leaf MLC with no backup jaws). The calculated planner dose distributions were compared with both the MapCHECK measurements and with calculations using a commercial planning system (Pinnacle^3, version 7.6) for several clinical cases. Comparison was done using the MapCHECK software in absolute dose mode with 3% dose error and 3-mm distance-to-agreement criteria. **Results:** The passing rate for most of the cases is above 95% with most of the failing points in the field edges. The calculation time for each field is about 5 sec using a personal laptop computer and is independent of field size. **Conclusions:** A fast algorithm has been developed for independent planar dose verification of IMRT plans as part of the IMRT quality assurance procedure. The algorithm was applied to two linac models with excellent results.

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SU-FF-T-44

A Practical DRR Reconstruction Technique for Removing Artifact Induced by Patient Respiration for Prostate Cancer Treated with IMRT

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Purpose: In our clinical practice, we often encounter prostate cancer patients who breathe heavily during CT simulation. This is particularly significant for overweight patients. Consequently, the DRRs reconstructed from these CT images show a sine wave type of artifact on the femoral and pelvic bones. This phenomenon is especially pronounced in the right and left lateral views, where the respiration amplitude is maximum, making patient setup verification based on these DRRs very difficult. In this study, we attempted to develop a practical reconstruction technique to remove this artifact efficiently. **Materials and Method:** A right lateral DRR was first computed using the acquired CT images. A sine wave function with proper amplitude and phase was used to model the breathing pattern as shown on the femoral bone on this DRR. This would allow us to determine the breathing amplitudes of each individual slices relative to the mean breathing position during a complete respiration cycle. The correct shift (or number of rows) of each slice relative to the mean breathing position was then determined by dividing the breathing amplitude by the pixel resolution. For each slice, the data matrix was resorted by shifting the matrix by the number of rows determined in the last step. The missing top rows (in the case of downward shifting) or bottom rows (in the case of upward shifting) were filled in with data from the nearest row. The new DRRs will then be computed from these resorted CT data. The proposed technique was implemented using MATLAB. **Results:** Comparison of original DRRs and the DRRs computed using proposed technique showed significant reduction in breathing artifact. The quality of these new DRRs was sufficient for patient setup verification. **Conclusions:** The proposed technique is practical and can effectively remove the sine wave artifact induced by respiration.

SU-FF-T-45

A Procedure for Correcting the Effect of Detector Properties On Measured Profiles of Small Field MV X-Ray Beams

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Purpose: Very small fields and segments of area less than one square centimeter are routinely being used for IMRT and stereotactic radiosurgery. Accurate measurement of beam profile is essential for treatment planning. Ion chambers with very small cavity radius, specialized diodes and films are commonly used for these beam data measurement. The purpose of this investigation is both to study the effect of the detector properties on the measured beam profiles of the small field MV x-ray beams and to apply the necessary correction to determine the real profiles. **Method and Materials:** Two ionization chambers with cavity radius of 2 mm and 1 mm, a stereotactic diode and XV film were used to measure the beam profiles of circular fields of stereotactic cones and small square fields defined by collimator jaws and MLC. The penumbra widths of the profiles were compared to study the effect of the physical properties of the detectors, such as, size, energy dependence and dose rate dependence on the measured beam profiles. The profiles measured by the larger ionization chamber were corrected for the detector size effect by using a semi-empirical procedure [1] and was used as the reference profile to derive the detector response function of other detectors with smaller size and better spatial resolution. The detector response functions were then used to correct the measured profiles of small fields. **Results:** The differences in the profiles measured by different detectors were significantly reduced after the profiles were corrected with detector response functions.**Conclusion:** The accuracy of the profile measurement of small therapy beams can be significantly improved when appropriate corrections are applied to take into account the variation of detector response in different regions of the beam.

[1] Kazi, A. et al., Med. Phys. (abstract) 31, 1908 (2004).

SU-FF-T-46

A Prototype Radiation Therapy Picture Archive Communication System (RT PACS) Design for Clinics Implementing IGRT

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Purpose: To report on the development of a prototype Radiation Therapy Picture Archive Communication System (RT PACS) needed for clinics implementing image-guided radiation therapy (IGRT). Methods and Materials: We have recently placed in clinical use (1) Elekta Synergy with kV Cone Beam CT (CBCT) and electronic portal imaging and (2) TomoTherapy HI-ART with MV CT. A third IGRT machine is scheduled for June 2006. Image series sizes of over 1 GB per study have been acquired. Responding to image storage needs, we have developed an RT PACS system using "commercial-off-the-shelf" components. System consists of a Storage Area Network (SAN) and specialized DICOM RT software. TeraMedica Evercore software is used to store and retrieve information via a DICOM query. The SAN is characterized by a three tier storage structure, allowing for fast access of the information used most often while keeping price reasonable by storing parts of data in slower areas. Access is provided via Logical Unit Numbers (LUN), each of which is associated with a quality of service, which determines position on the hardware and thereby access speed. Software is enabled to automatically move less frequently used files to slower areas, thereby allowing for seamless archiving. **Results:** DICOM data sets were successfully exported to the RT PACS. Users can search the database and retrieve stored images and RT PLANS. A web-based viewer allows users to logon remotely from anywhere on the Hospital LAN, or if connected remotely thru VPN to view patient's treatment plans securely. **Conclusions:** The size of patient images sets increases dramatically with the use of CBCT and tomotherapy MV CT. Daily use of these IGRT capabilities will result in our current servers filling to capacity in less than 6 months. The prototype RT PACS appears to meet our needs regarding data storage, workflow, HIPPA, EMR and connectivity.

SU-FF-T-48

A QA Device to Perform End-To-End Spatial Accuracy Tests of Target Irradiation in Stereotactic Radiosurgery

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Purpose: To ensure the sub-millimeter accuracy of Radiosurgery treatments, it is imperative to evaluate and monitor the errors associated with the whole treatment process. We have designed a QA Phantom that makes it possible to perform such accuracy testing. **Method and Materials:** Our plastic phantom was designed such that it can be mounted in the same stereotactic frame which is fixed on the patient during imaging and irradiation. Small targets at several locations in the phantom can be interchanged depending on the imaging modality used for imaging. Targets made out of Cu are used for CT imaging, or a drop of dilute copper sulfate in a small absorbent medium for MRI. The phantom in the frame and the localization box with the fiducial system is imaged simulating a patient. The images are reconstructed in the treatment planning system and the irradiation set up data for the targets are used for positioning the phantom in the radiation unit. During the irradiation the target is replaced by Gafchromic film, the exact location of the target is marked on the film with a pinhole that was designed to mark the film at the same location as the imaged target. By irradiating the phantom with small cross section beams focused at the target a spot is created on the film. The accuracy of the irradiation given at the target location is evaluated by the deviation of center of the spot on the film from the pinhole. **Results & Conclusions:** Several end-to-end tests were performed for our Gamma Knife unit to demonstrate overall accuracy of the process. Our phantom provides a direct test of the variation in the target irradiation as resulted by possible variations introduced in all the stages of the process of the stereotactic treatment such as imaging, treatment planning, and radiation delivery.

SU-FF-T-49

A QA Test to Check MLC Carriage Calibration

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Purpose: The leaf span for a Varian MLC is 15 cm. Fields larger than this in the leaf motion direction must be split into multiple ports with a "carriage shift" between ports. Leaf position is a function of both carriage position and leaf position within the carriage. The carriage position is dictated by the outermost leaf position, and the carriages do not move during radiation delivery. We have developed a test to assess carriage positioning accuracy by comparing the same abutting MLC-shaped fields both with and without carriage motion between the delivery of the two fields. **Methods and Materials:** A 14 cm wide x 40 cm long field was split into two 7 cm wide rectangular ports shaped by the MLC. Width is defined in the leaf motion direction. These two fields were delivered using two separate static MLC files, then using a single DMLC file. In the former case, the carriages move while the leaves remain stationary with respect to the carriages. In the latter case, the carriages remain stationary while the leaves move with respect to the carriages. Kodak XV film was taped to the collimator face for both cases and compared. **Results:** Both films appeared identical upon visual inspection. A quantitative analysis of the profiles was performed using the RIT software system. Comparison of the profiles revealed that the FWHM of the abutting region agreed to within 0.2 mm between the two films. **Conclusion:** If accuracy of leaf calibration has been demonstrated, differences between these profiles would imply carriage miscalibration. Carriage miscalibration would result in mispositioning of all leaves within the carriage, thereby causing significant dose delivery errors. This carriage calibration test could be performed routinely as part of the QA procedure for MLCs used for IMRT delivery.

SU-FF-T-50

A Quantitative Dose Attenuation Analysis Around Fletcher-Suite Device Due to Stainless Steel Tube for HDR Brachytherapy: Monte Carlo Calculations and MOSFET Measurements

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Current intracavitary therapy planning system for brachytherapy treatment of cervical and endometrial cancers using Fletcher-Suite Device (FSD) typically implements Manchster point system for dose delivery. Also, all

available treatment planning systems neglect the attenuation effect from stainless steel (SS) tube, leading to potential inaccuracies in dose distributions. Previous publications only reported the dose reduction from the cylinder SS tube. To the best of our knowledge, the attenuation effect of SS tube from Fletcher-Suite Device has not yet been reported. This investigation uses Monte Carlo simulations (MCNP) to construct a typical geometry of FSD and compare the doses delivered to Point A in Manchester System with and without SS tube. This will delineate quantitatively the inaccuracies in dose distributions in three-dimensional space. The source geometry was that of the VariSource wire model VS2000. The Fletcher-Suite Device was that of the Varian medical system. In this case, the bending angles of tandem and colpostats are 15^{o} and 120^{o} respectively. We assign 10 dwell positions to the tandem and 4 dwell positions to right and left colpostats each. Measurements using MOSFET were performed in water, using a water equivalent jig for precision positioning of FSD and other instruments. Typical dose delivered to point A were determined according to Manchester System. Based on our preliminary computations, the dose reduction to point A was shown to be at least 3%. So this effect of FSD on patient dose is of concern. Good agreement was observed between simulations and measurements to within the acceptable error for MOSFET dosimetry (0.9%~2.8%). Techniques used to develop the FSD design in MCNP in 3D space and dosimetry results obtained for FSD system and vaginal cylindrical tube will be presented.

SU-FF-T-52

A Robotic Platform for Image-Guided Brachytherapy (IGBT)

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Purpose: In image-guided brachytherapy (IGBT), accurate placement of needles and radiation sources is a major challenge. In traditional prostate brachytherapy, for example, needles are introduced through fixed, parallel holes of a template where the maneuverability of the needle is extremely limited. The accuracy of needle placement and seed delivery is subject to variation with clinician technique, such as deflection force and needle rotation. We present a robotic platform for IGBT, a semi-automated 14 degree-of-freedom (DOF) robotic system, designed and fabricated for performing prostate brachytherapy with radioactive seeds. **Method and Materials:** The IGBT system consists of two main modules: (1) a 7 DOF positioning module, and (2) a 7 DOF surgery module. The positioning module has a 2 DOF cart and a 5 DOF platform. The surgery module includes a 2 DOF ultrasound probe driver, a 3 DOF gantry robot, a 2 DOF needle inserter and a seed pusher. All motions of the surgery module are motorized. This system incorporated numerous important data and methods garnered from *in-vivo* measurements during actual brachytherapy procedures. Various techniques to enhance precision of needle insertion and seed delivery have been implemented into the system, after extensive verification via phantom experiments. Three force-torque sensors were incorporated for tracking the forces on the needle to detect pubic arch interference and to improve robot control. Rigidity and factor of safety of the mechanical structures have been analyzed using finite element method. The system has provisions for feedback of various states (position, velocity and force), which will be useful to improve needle insertion and seed delivery accuracy, consistency and efficiency. **Results and Conclusion:** Preliminary experimental results demonstrate highly accurate (sub-millimeter) and consistent placement of brachytherapy needle. Extensive experiments have been conducted to evaluate performance of this prototype system for IGBT. **Acknowledgment:** Work supported by NIH/NCI Grant No. R01-CA91763.

SU-FF-T-53

A Robust Approach to IMRT Optimization

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Purpose: To demonstrate the advantages of using a robust optimization methodology in IMRT treatment planning to mitigate the effects of intra-fraction uncertainty induced by breathing motion. **Method and Materials:** A robust optimization framework was developed to directly incorporate breathing uncertainty into IMRT optimization. Data for this model was obtained from four patients, totaling 95 traces of motion data gathered from an external marker. This data was used to create a "nominal" probability density function (PDF) that was used in the planning, and also "error bars," which outlined the allowable deviations from the nominal PDF. A computer phantom was used to evaluate the robustness of an optimized beamlet solution in the situation where the realized PDF differed from the nominal (planned) one. The robust formulation was compared to two other formulations: a nominal formulation, which did not take uncertainty into account, and a margin formulation, which used an optimized margin to combat uncertainty. **Results:** With uncertainty in the PDF, the nominal solution led to significant hot and cold spots within the tumor. Both the robust and margin solutions were able to deliver the required dose to the tumor under the realized uncertainty, however, the robust solution did so while delivering approximately 38% less dose to the healthy tissue. More fundamentally, the robust formulation was mathematically proved to be a generalization of both the nominal and margin formulations, thus defining a "continuum of robustness" that allows the user to modulate his or her conservatism to customize treatment plans based on the case at hand. **Conclusion:** This work demonstrates the potential of using robust optimization in IMRT treatment planning to improve healthy tissue sparing while maintaining tumor coverage in the presence of uncertainty, and also the flexibility afforded to the treatment planner to make suitable decisions regarding trade-offs of conflicting objectives.

SU-FF-T-55

A Semiempirical Procedure for Correcting Detector Size Effect On Clinical MV X-Ray Beam Profiles

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Purpose: To develop a procedure to determine the real profiles of high-energy x-ray beams by removing the detector size effect from the measured profiles. **Method and Materials:** The proposed procedure is based on the combination of analytical deconvolution formalism of Garcia-Vicente *et al.* [1] to determine real profile and the experimental observation of the linear relationship between the penumbra width and the inner radius (r) of the detector by Dawson *et al.* [2]. Measured profiles can be corrected by shifting the position of each measurement point by a specific amount determined from available theoretical and experimental knowledge. The measured dose by the detector is related to the second derivative of the dose at that point. Therefore, the amount of shift can be considered to be proportional to the second derivative of the real profile at that point. The value of the shift at the 90% or 80% dose level is experimentally known [2] to be equal to 0.5r. The constant of proportionality can thus be determined from the value of this shift and the second derivative of real profile at the corresponding location, which can be obtained by using the analytical expression for the profile and the measured dose at the shifted location. The procedure was tested by correcting the profiles of 6 MV x-ray beams measured by a chamber with cavity radius of 2 mm. **Results:** The corrected profiles match very well with that measured with a stereotactic diode, and the corrected penumbra widths agree with the results of earlier investigations.**Conclusion:** The proposed procedure is found to be accurate and can be used to derive the real profiles of clinical high-energy x-ray beams. [1] Garcia-Vicente, F. *et al*., Phys. Med. Biol. 45, 645 (2000). [2] Dawson, D. J. *et al*., Med. Phys. 13, 101 (1986).

SU-FF-T-56

A Simple Method for Selecting a Pinnacle IMRT Point for Verification in RadCalc

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Purpose: To select a reference point in a low dose gradient region of an IMRT treatment plan to enhance the MU and point dose agreement between Pinnacle and RadCalc. **Method and Materials:** After generating an IMRT plan within Pinnacle, we export it to RadCalc for a second check of the MU's. Frequently, the MU difference is significant for a plan with split beams or isocenter out of the field. In contrast to Pinnacle, RadCalc displays a coordinate grid over its BEV fluence. By utilizing this feature for the problematic beams, we selected reference points in low gradient regions of each beam's fluence map. In RadCalc's BEV, we identified the coordinate shifts relative to isocenter of the preferred points. We generated

an Excel spreadsheet to calculate the updated coordinates in Pinnacle's 3-D CT-based coordinate system to reflect the desired point shift in RadCalc. These new coordinates were then entered in Pinnacle for the patient plan and re-exported to RadCalc. The modified MU and dose comparisons within RadCalc generally fell within 5% per beam. **Results:** While this method adds a few extra steps to the planning process, it provides a way to choose reference points whereby the MU's and point doses between Pinnacle and RadCalc are likely to agree within a few percent, and it makes determining the coordinates of such points a reasonably efficient process. **Conclusion:** RadCalc is a useful program for verifying IMRT MU's and point doses generated by Pinnacle. However because Pinnacle exports the user selected reference point (typically isocenter), there are common conditions in which RadCalc understandably determines large percent differences in calculations. Our method uses RadCalc's fluence map along with a spreadsheet to determine the Pinnacle coordinates of a preferred calculation point, rather than "guessing" where to place a POI to bring about better calculation agreement.

SU-FF-T-57

A Simple Method of Calculating Isocenter Dose From Measured D-Max Dose of IMRT Field

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Purpose: To provide a simple method of calculating isocenter dose from the measured d-max dose of IMRT fields, then compare the result dose with the calculated isocenter dose from the treatment planning computer system in the patient geometry. **Method and Materials:** IMRT plans are developed with Varian Eclipse, and delivered on two Varian 21EX treatment units by using sliding window technique. We use a device with a film holder and a diode holder about 2 cm below the film at central axis of the field. This device is mounted at the block tray level. A Kodar X-OMAT V film gives fluence map and effective field size. A diode (SunNuclear RF-IVD) reading gives the d-max dose. Using the effective field size and the depth from the plan, one can find the effective TMR. The following formula gives the relation between dose at d-max with 100 SSD and dose at isocenter. $Dose\_iso = Dose\_dmax \times TMR[(SAD + dmax)/SAD]^2$ **Results:** We have used this method to calculate isocenter dose from diode readings for about 150 IMRT plans. The average differences between QA isocenter dose and plan isocenter dose are: -0.5 % with a standard deviation of 2.3% for 80 prostate plans using 6 MV photon beams; 2.4 % with a standard deviation of 1.5% for 36 prostate plans using 10 MV photon beams; 2.2 % with a standard deviation of 2.3% for 40 IMRT plans treating sites other than prostate using 6 MV photon beams. **Conclusion:** We have good agreement between the QA isocenter dose and isocenter dose from treatment planning system. Unlike IMRT QA methods using phantom, our method also checks a point dose with patient geometry; Unlike MU calculation programs, our method also checks the delivery of the treatment machine.

SU-FF-T-58

A Simple Optimization Technique Useful for Dynamic Arc Radiosurgery Planning

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Purpose: To demonstrate a simple but efficient optimization technique improving the conformity, uniformity, and tumor coverage for SRS plans with equally weighted dynamic conformal arcs. **Material and method:** Dynamical arc radiosurgery in Brainscan planning shapes the arcs every 10 degrees based on the limited 2D projection. Although desired shapes of arc segments can be automatically achieved through user-defined margin around the target, the plan doesn't fully consider the 3D dose distribution information. The conformity with equally weighted arcs is far less optimal for highly irregular target. To improve it, a simple and efficient technique was developed to fine tune the plan. With initial isodose distribution in each slice, one hot and one cold dose regions were drawn as two new structures. The hot structure is where the prescribed isodose line is outside the PTV, and cold one for inside the PTV. Then on beams-eye view of the individual arcs, simply opening the leave to the cold structure and closing the leave to hot structure modified the multileaf apertures. The procedure could be repeated until a satisfied plan was obtained. **Result:** Analyzed total nine cases. Average conformity index was increased by 10% and the hotspot volume was reduced by 15% after two iterations. For the highly irregular case, it can be 23% conformity enhancement and 36% hot dose decrease. The improvement for spherical shape target is not significant, 1.2% conformity increment and 2.6% hotspot reduction. **Conclusion:** Manual fine-tune technique is useful for improvement of dose distribution conformity, tumor coverage and eliminated the hot spot for highly irregular targets. The plan time can be reduced with users' experiences. This technique is better using as a fine adjustment. The initial arc configuration such arc ranges, separation, and number should be considered first.

SU-FF-T-59

A Simple Scoring Method of Dose Homogeneity for IMRT Treatment Planning

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Purpose: The goal of this study was to develop new index for effectively evaluating dose homogeneity with the target-volume dose–volume histogram (DVH) of intensity-modulated radiotherapy (IMRT) treatment plans. **Method and Materials:** The newly defined homogeneity index for assessing dose homogeneity in a target volume, named the *sigma*-index (*s*-index), was developed using a normalized differential-DVH (*d*DVH) with statistical analysis. **Results:** The *s*-index, determined as the standard deviation of the normalized *d*DVH, was found to vary from 0.80 to 3.15 for the DVHs of brain tumor at out institution. It has been shown that the dose homogeneity for target volume could be also evaluated based on the functional approximation of a target volume DVH to a modified step function and a normalized differential-DVH to a Gaussian function. The *s*-index was compared with these functional approximations in addition to the conventional homogeneity indices. **Conclusions:** The results showed that the *s*-index gives a consistent method for quantifying the degree of homogeneity and has been demonstrated to be more accurate than the conventional methods in evaluating the dose homogeneity. A guide line of the treatment plan based on dose homogeneity is discussed with relation to equivalent uniform dose (EUD).

SU-FF-T-60

A Simplified Frame Work Using Deep Inspiration Breath-Hold (DIBH) for the Treatment of Left Breast Cancer with Improved Heart Sparing

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Purpose: To develop a simplified frame work using deep inspiration breath-hold (DIBH) for left breast treatment. **Materials and Methods:** The current version of Varian's RPM system was rarely used in amplitude gating mode, especially with breath hold. The major reason is that the breathing amplitude is much less reproducible than breathing phase. Further, the same signal captured by the infrared camera in simulation room and that in treatment room could be different in amplitude. In this study, we presented a simplified frame work to improve the reproducibility of patient's breathing amplitude. First, an aqua-plastic body mask of 1.0-1.5 in wide was made right before patient's simulation while the patient is in DIBH. The body mask was set at umbilicus right superior to the marker box. It will then be used to guide the patient herself for DIBH. The DIBH signal is also displayed on a computer monitor set close to patient, which is a duplicate display of the DIBH signal in the RPM computer. The patient can see her own signal and can therefore guide her breath such that relatively constant amplitude can be achieved. **Results:** The frame work was tested by a few volunteers and all agree that the system is feasible for left breast treatment. The DIBH can last 15-35s with good constant amplitude. In case the captured amplitude is different in treatment room, the two gating threshold lines set in simulation can be adjusted overlay to the DIBH signal before treatment.**Conclusion:** The system is feasible for the treatment of left breast cancer with DIBH. Further improvement can be made by wiring the gating cable through patient using two electrodes; one on patient's body and the other on the guiding mask so that the amplitude-gated CT scans and treatment can be actively controlled by patient herself.

SU-FF-T-62

A Stereotactic System with a Non-Stereotactic Component: A New Perspective

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Purpose: A non-stereotactic component has been incorporated in the XKnifeRT (Radionics) stereotactic system. This allows the circular cones/arcs to be used for cranial applications without the actual stereotactic frames but retaining the advantage of conformal distributions. Extracranial applications include an initial 3D non-stereotactic followed by a stereotactic boost, all in one system thereby allowing a composite dose distribution to be viewed. **Method and Materials:** A 79 year old male with recurrence of a prolactin-secreting pituitary adenoma was fitted with a mask and marked with three fiducials so that these appeared in the CT scan (2 mm slices). This non-stereotactic CT scan was transferred to the XKnife RT treatment planning system and the "non-stereotactic" localizer selected. The CT slice that shows the external markers was brought in the field of view and the non-stereotactic axes positioned so that the horizontal axis passes through the left/right markers and the vertical axis passes through the anterior. This provided the origin for the system and the treatment plan was accomplished using a 4 cm cone and 5 arcs. The prescription was set at 5040 cGy in 28 fractions. At the linac, the patient was set up using the three markers on the mask rather than the usual stereotactic hardware. Frequent orthogonal portal images were acquired to ensure good patient reproducibility. **Results:** The dose distribution obtained by utilizing circular cones and arcs is clearly far superior and allows for sparing of the normal brain when compared to static 3D fields. However, the patient day to day reproducibility is, as expected, considerably inferior when compared to the stereotactic frames. However, this combination proved very beneficial in this situation where the patient could not be fitted into the stereotactic frame. **Conclusions:** The non-SRT component in XKnifeRT provides considerable flexibility in using the stereotactic technology itself.

SU-FF-T-63

A Study of Effectiveness of Stereotactic Head Frame Distortion On the Gamma Knife Automatic Positioning System by Stress of Screw Fixation

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During routine Gamma Knife radiosurgery procedure, it was noted that the Automatic Positioning System (APS) (Elekta Inc) did not always function as expected for some patients This caused the plans to be readjusted for use of trunnions which greatly lengthens the treatment time in most cases. After investigation of those repeated APS operation failures, the reliability of APS was extensively tested by performing a series of measurements to determine head frame distortion. Measurements on a fabricated hard wood phantom using a range of torques (2-20 in·lbs) were applied to screws which fastened the head frame into the skull of the patients for Gamma knife treatment. The ability for the Leksell frame to lock into APS was used as the endpoint to determine whether the APS would operate clinically. A calibrated digital torque wrench was applied in those measurements. The magnitude of the distortion on the head frame has been measured by using calipers between the two frame members (Z-bars) which are attached to the sides of head frame bi-laterally. In the clinical application, the acceptable torque upper limit was15 in·lbs which was the maximum applied to the screws in 26 clinical cases and has been used to predict the success application of the phantom measurements. For 14 Gamma Knife cases, if a frame displacement was greater than 1.5 mm, the APS would not operate. If frame displacements under 1.5 mm, the APS operated in 12 cases. A linear correlation coefficient (r^2) was found to be 0.94 for the fitting of the data to a line.

SU-FF-T-64

A Surface Based Method for Adaptive Treatment Planning in Real-Time - Application to Prostate IMRT

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Purpose: To develop a method for adaptive treatment planning in real-time based on fast structure segmentation using deformable surface model and surface based dose optimization. **Methods and Materials:** A parametric surface model is used for target segmentation with in-room acquired CT images, starting from a superimposed template structure on the image dataset. The 3D surface of the target is obtained as tensor product of B-spline curves, and the 2D contours are generated using B-spline interpolations for direct manipulations. The interpolating points and cross-sectional contours are displayed in multiple views of reformatted CT slices. The target surface is updated in real-time following the shifts of interpolating points. The algebraic representation of the target uses polar angle and height in cylindrical coordinates as parameters. The surface normals are calculated, particularly on the portion interfaced with a critical structure, such as the rectum. The dose and the dose gradients on the target surface are calculated. Adaptive dose optimization is performed without the outline of critical structures. The optimization conditions are that the surface dose is uniform; the surface dose gradients are normal to the surface for dose conformity; and the gradients on the portion interfaced with critical structures are maximized for the best critical structure sparing. **Results:** The modeled prostate surface agreed with axial contours within 2 mm. Optimized intensity maps based on surface-based conditions intensity optimization were similar to that of an optimized template plan, thus small adaptive changes of the plan could be made. **Conclusion:** The feasibility of real-time treatment planning relies on fast structure segmentation and characterization of the target volume changes from the simulated dataset. B-spline surface model gives an accurate and smooth representation of the target and simple surface-based optimization conditions can be applied for efficient for real-time planning.

SU-FF-T-66

A Technique for Cone-Beam CT-Guided Stereotactic Body Radiation Therapy

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Purpose: To develop and assess a technique using cone-beam CT (CBCT) to localize treatment targets for stereotactic body radiation therapy (SBRT). **Material and Methods:** Patients selected for SBRT had 3-D or 4-D CT simulation with immobilization. GTV, CTV, ITV, and PTV were identified for treatment planning. Intensity-modulated radiation beams, multiple 3-D conformal beams, or dynamic conformal shaped arcs were designed (physician preference) and delivered using a Varian 21EX with 120-leaf MLC. Pre-treatment CBCT images (acquired over sixty seconds) were registered to the planning CT based on target soft tissue and bony structures. After the physician confirmed the potential deviations of the treatment target, the couch was automatically shifted for positioning correction. Radiographic images (kV, MV or CBCT) were taken before and after beam delivery to assess for potential intra-fraction motion. **Results:** Five patients with lung, liver, and spine lesions received 18 fractions (all 3 fractions except one 6 fractions) using this technique. Pre-treatment CBCT images were successfully obtained for 17 fractions. Compared to traditional 2D matching using bony structures (tumor are usually not visible), use of CBCT, which is essentially imaging ITV, is able to correct target deviation from 1 mm to 15 mm with an average of 5 mm. The comparison on pre-treatment and post-treatment radiographic images demonstrated an average 2 mm deviation (ranging from 0-4 mm), suggesting that better immobilization might further improve the positioning accuracy. Typical total "in-room" times for the patients are about 1 hour. **Conclusion:** CBCT-guided SBRT is reasonable and allows for alignment based on 3-D anatomical information prior to treatment.

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SU-FF-T-67

A TG43 Methodology to Describe Iridium-Wires with Variable Length

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The use of Iridium wire has a long history in the application of radiation therapy. A number of legacy systems still support the planning of this treatment. Newer brachytherapy planning systems currently rely on a methodology based on the recommendations of the AAPM task group no. 43 (TG43). The aim of this task group was to provide a framework for the application of point like (or near point like) brachytherapy sources. However, in clinical practice, the Iridium wires are cut to the needed length necessitating an description of sources with variable length. It is clear that the TG43 methodology implies a fixed source length. In this work we aim to provide an extension of the TG43 framework by allowing the length of a given source to vary. To this end monte carlo simulation (MCNPX2.6.0A) of Iridium sources of lengths between 1 and 14cm were performed. Dose distributions around the source in water and in vacuum (activity determination) were calculated. From this data we derived the activity, the dose rate constant and the radial function. The activity (Air Kerma measured at 1m distance) showed no variation as a function of the source length(L). The dose rate constant followed a relatively simple pattern which could be fit with a function of the form: $\frac{a}{(L+c)^c}$. The radial dose rate could be fit with a function of the form $\frac{A(L)r^{B(L)}}{1+C(L)r^{D(L)}}$. The radial function was subsequently obtained by taking the geometrical function into account. The variables A,B, C, and D showed smooth variation as a function of L. Allowing interpolation to predict radial functions of lengths for which no monte carlo simulations were available. We hope to extend this work to include the anisotropy terms in the near future.
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SU-FF-T-68

A Three-Dimensional Quantitative Dose Reduction Analysis in MammoSite Balloon Due to Radiopaque Iodine-Based Contrast Solution in Ir-192 for HDR Brachytherapy: Monte Carlo Calculations and MOSFET Measurements

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Current treatment planning systems (TPS) for partial breast irradiation (PBI) using MammoSite brachytherapy applicator often neglects the effect of inhomogeneity, leading to potential inaccuracies in dose distributions. Previous publications have investigated only a planar dose perturbation along the bisector of the source. This investigation expanded to include the attenuation-corrected radial dose and anisotropy functions and incorporates them into a treatment planning system in a form parallel to the updated AAPM TG-43 formalism. This will delineate quantitatively the inaccuracies in dose distributions in three-dimensional space. The changes in dose deposition and distribution caused by increased attenuation coefficient resulted from iodine-based contrast solution are quantified using MCNP Monte Carlo simulations in coupled photon/electron transport. The source geometry was that of the VariSource wire model VS2000. Concentration of the iodine-based solution was varied from 5% to 25% by volume, a range recommended by the balloon's manufacturer. Balloon diameters of 4cm through 6cm were simulated. Measurements using MOSFET were done in water, using a water equivalent jig for precision positioning of balloon and instruments. Dose rates at the typical prescription line of 1cm away from the balloon surface were determined in different polar angles. According to the computations, the dose rate reduction throughout the entire region of interest ranged from 0.33% for the smallest balloon diameter and contrast concentration to a maximum of 6.29% for the largest balloon diameter and contrast. Good agreement was observed between simulations and measurements to within the acceptable error for MOSFET dosimetry (0.9%~2.8%).

SU-FF-T-69

A Tool for Graphical Display of TCP Information in Regions of Dose Inhomogeneity

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Purpose: It is well known that the overall Tumor Control Probability (TCP) can be strongly influenced by localized cold spots in the underlying dose distribution. To evaluate the clinical significance of cold spots, we propose two new indices which are derived from TCP, but which depend on spatial location and can be overlayed as isolines on the patient's anatomy. Methods and Materials: The cumulative TCP index is calculated as a product of tcp_i values which are locally computed at each voxel: $TCP = \prod_{i=1}^{i=n} tcp_i$. Assuming that the treatment planner sets a cumulative TCP target, we argue that the goal of the treatment planning can be re-formulated as follows: *to maintain a uniform distribution of locally computed* tcp_i *throughout the treatment volume.* The re-formulation allows us to calculate *maximum local density of clonogenic cells that is consistent with the treatment objective of the cumulative TCP.* The logarithm of this density can be overlayed on the patient's anatomy as isolines, thus quantifying the change in the effectiveness of the treatment in areas of in-homogenous dose. **Results:** The Clonogen Density Index (CDI) is defined as $c_i = \frac{\alpha(BED_i) + \ln[-\frac{\ln(TCP)}{V_{tgt}}]}{\ln(10)}$, where V_{tgt} is the target volume, and the TCP is the desired Tumor Control Probability. The Differential Clonogen Density Index (dCDI), is defined as: $\partial c_i = \frac{\alpha(BED_i - BED_{ref})}{\ln(10)}$ where BED_{ref} is derived from the dose prescription. The dCDI index quantifies voxel-to-voxel change in the maximum clonogen density, relative to a reference value. **Conclusion:** We introduce two new indices which measure maximum clonogen density that can be supported by the treatment, given the treatment objective of a cumulative TCP. These indices can be used to evaluate plans with significant regions of dose in-homogeneities. They should be seen as complementary to the TCP index.

SU-FF-T-70

A Treatment Planning Study of Liver Cancer Treatments with a Flattening Filter Free Linear Accelerator

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Purpose: Our preliminary studies have shown that the removal of the flattening filter from the beam-line of a medical linear accelerator increases the dose rate, reduces head scatter and reduces dose outside the treatment volume. Although, in principle, the filter is unnecessary when a multileaf collimator is present, it remains to be seen whether treatments with unflattened beams are clinically feasible. In this study we investigate the application of flattening filter free photon beams for the treatment of small liver cancer tumors to determine if these beams offer an advantage for respiratory-gated radiotherapy. Methods and Materials: This is a treatment planning study. We created plans using Eclipse 8.0 (Varian Medical Systems), which we commissioned with measured (6 MV, 18 MV) and Monte Carlo (10 MV) data for a Clinac 21EX linear accelerator, operated with and without a flattening filter. We selected several conventional 3D conformal treatment plans for flattened beams with field sizes not exceeding 10 cm × 10 cm. These were then compared with treatment plans, including 3D conformal plans and IMRT plans, developed with unflattened beams. **Results:** Dose distributions for treatment volumes and nearby critical structures were typically equivalent for the intensity-modulated plans with flattened and unflattened beams. The number of monitor units required to deliver the same dose was much lower in the plans with unflattened beams. For example, at 18 MV the total number of

monitor units in the intensity-modulated plans with unflattened beams was about 1/2 of those in the conformal 3D plans with flattened beams. **Conclusion:** In this study we show that clinically acceptable treatment plans for liver cancer can be obtained with unflattened beams. With respiratory-gated radiotherapy, the high dose rates achieved with unflattened beams may shorten the overall treatment time dramatically. **Conflict of Interest:** Research sponsored by Varian Medical Systems

SU-FF-T-71

A Useful Tool Developed for Trial Comparison and Developing Composite Plan Between Tomotherapy and Pinnacle

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Purpose: To develop a software tool for processing the dose matrix from the Hi Art Tomotherapy unit for trial plan comparison and summation of doses between plans. **Method and Materials:** A Visual C++ tool was developed in order to manipulate the dose matrix generated by the Tomotherapy planning station. The tool reads in the tomotherapy dose matrix which is then exported into the Pinnacle^3 planning station. Two different tomotherapy trials can be compared dosimetrically or a composite tomotherapy plan can be computed by summing together multiple tomotherapy trials. A Pinnacle^3 script is written out by the tool which allows the Pinnacle planning station to setup the appropriate parameters and import the tomotherapy data. The Pinnacle tools can then be used to perform trial comparison, show DVH, isodose distribution etc. Eight patients treated by Tomotherapy have been selected randomly as candidates for this study. The ages of the patients ranged from 15 years to 72 years. Two female patients and 6 male patients were selected. The PTV volumes ranged from 23.10 cm^3 to 1059.90 cm^3. The treatment locations included head and neck, larynx, tonsil, lung, prostate, abdomen, brain, and cranio-spinal. **Results:** Eight Tomotherapy patients plans were successfully imported into Pinnacle^3 planning station using our TomoExport software tool. Plan comparisons have been performed considering biological uniform dose and integral dose. **Conclusion:** A Visual C++ tool has been developed for processing the dose matrix generated by Tomotherapy treatment planning station and export it to the Pinnacle^3 treatment planning station. The tool has been used for eight patients treated with Tomotherapy and the plans have been compared against the Pinnacle^3 IMRT plans. The TomoExport tool is useful for both clinical and research applications allowing us to perform plan comparisons between Tomotherapy and Pinnacle^3 and develop composite plans.

SU-FF-T-72

Absolute Rectal Volumetric Dose as a Meaningful Predictor to Its Late Side Effect in Prostate IMRT

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Purpose: To investigate a meaningful correlation between rectal volumetric doses and the rectal late side effect in prostate IMRT. **Method and Materials:** Six cases with complaints of prolonged rectal bleeding after one year of prostate IMRT course were analyzed. The DVH's were compared with the control group comprised of 14 similar IMRT cases without late rectal side effects. The follow-up time was 24-45 months. In each case, a total of 75.6 Gy radiation dose was delivered in 32 fractions using 7-field 18 MV photon beams. All CTV's were delineated on fused MR/CT images. The posterior margins of PTV's were 7 mm for initial 45 Gy and 4 mm for the 30.6 Gy reduction dose. Nonexclusively, PTV protruded into the anterior portion of rectal wall. During patient daily setup, an ultrasound targeting system was employed to ensure the accuracy. **Results:** There were no significant deviations seen in relative volumetric DVH's between the two groups for rectal D_5 through D_{50} ($p > 0.05$). However, DVH's for absolute rectal volume indicated significant higher values ($p < 0.01$) in the group with late rectal side effect, as seen in table1. **Conclusions:** No statistical meaningful correlation was found in our data between relative volumetric DVH and the occurrence of late rectal side effect. Rectal DVH using absolute volume is suggested by this study to be a more sensitive indicator to predict late rectal side effect in prostate IMRT. This study is valuable for future follow-ups and investigations.

Table 1. Rectal Mean Dose (cGy) in Prostate IMRT

Rectal Volume	Test Group (No=6)		Control Group (No=14)		t-test
cm3	Mean	SD	Mean	SD	p (2 tails)
0	9083		8473		0.000
5	7489		6959		0.019
10	6890		5987		0.001
15	6313		5351		0.002
20	5878		4754		0.000
25	5349		4201		0.000
35	4403		3220		0.001
45	3205		1927		0.008

SU-FF-T-73

Accounting for Tissue Heterogeneities in Head and Neck IMRT Plans Increases Planning Target Volume and Spinal Cord Doses

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Purpose: Using TLD measurements in an anthropomorphic phantom, we previously demonstrated that the presence of heterogeneities causes an average 5.1% dose increase compared to the dose calculated by CORVUS' pencil-beam algorithm without heterogeneity correction. In this treatment planning study, we investigated the dosimetric effects of heterogeneities on clinical head and neck IMRT plans. **Method and Materials:** Ten CORVUS plans for five nasopharynx (NP) and five base of tongue (BOT) tumors were recalculated using the convolution/superposition algorithm of Pinnacle^3 6.2b. In contrast to the CORVUS algorithm used in our clinic which assumes a homogeneous water-equivalent patient, the convolution/superposition algorithm accounts for the effects of heterogeneities by converting CT numbers to electron densities. Dose volume histograms were compared for the Pinnacle^3 and CORVUS plans. To characterize tumor coverage, the D_{95} and V_{105} were calculated for the PTV. The maximum doses to the spinal cord were also compared. **Results:** The D_{95}, V_{105}, and spinal cord doses calculated by Pinnacle^3 following heterogeneity correction were larger than CORVUS doses for all ten patients. The D_{95} increased by an average of 2.5% (2.9% for NP and 2.2% for BOT tumors). The V_{105} increased by an average of 57.5% (60.2% for NP and 54.8% for BOT tumors). Increases in V_{105} ranged from 28.5% to 71.9%. Spinal cord doses increased by an average of 4.5% (4.5% for NP and 4.6% for BOT tumors) with a range of 0.8% to 8.5%. **Conclusion:** PTV coverage was minimally changed but the dose inhomogeneity within the PTV increased. The increased PTV dose inhomogeneity was larger by 5.4% in the NP tumors compared to the BOT tumors. Spinal cord doses were systematically underestimated by CORVUS. Overall, the differences between NP and BOT treatment plans were minimal. This was probably due to the similarity of the initial PTV volumes for the two sites.

SU-FF-T-74

Accuracy & Precision of An IGRT Solution

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Purpose: To establish the overall accuracy and precision of an image-guided radiotherapy treatment strategy. **Method and Materials:** A perspex head & neck phantom developed in-house for the verification of IMRT techniques was used to test an image guided radiotherapy treatment. The treatment involved the imaging of the phantom in the treatment position, followed by the delivery of an IMRT plan designed to spare salivary function. The complex IMRT plan involved five step-and-shoot fields with a total 65 segments delivered at 6MV. The phantom was not moved between the imaging and delivery phases of the experiment. The dose was measured at six points distributed in the phantom simultaneously via the use of micro-mosfets. Development of the phantom used in the experiment will eventually allow up to 20 points of interest being independently measured. As the overall accuracy of the treatment was sought the dose from the whole treatment was considered. Doses from individual beams were not analyzed. **Results:** Planned dose to the 6 micro-mosfets ranged from 220cGy to 350cGy with a dose prescription of 440cGy per fraction to the treatment isocentre. The measured doses were on average within 0.5% (±1.2%) when compared to planned doses. No differences greater than 2% were found in the investigation. Repeat experiments without moving the phantom demonstrated reliable delivery of the IMRT plan with a standard deviation of 0.5% from the average of the mean. **Conclusion:** A system has been developed to test the accuracy and precision of an image-guided radiotherapy treatment. It has been

confirmed that the accuracy of a complex IMRT dose delivery using an image-guided approach using an Elekta Synergy linac is ±2% in dose. The precision of the delivery system was demonstrated to be within 1% (2SD). **Conflict of Interest:** This research is partly funded by Elekta.

SU-FF-T-75

Accuracy Assessment of a Non-Invasive Image Guided System for Intra-Cranial Linac Based Stereotactic Radiosurgery

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Purpose: To assess the total system accuracy of a non-invasive image guided technique for intra-cranial radiosurgery. **Method and Materials:** To test the system three fiducials were placed in a Rando head phantom in cerebellar, mid-brain and lateral-frontal locations. A stereotactic mask system by Brainlab was used for immobilization. Positioning was based on the Novalis Body system consisting of two kV x-ray cameras with amorphous silicon detectors and an IR tracking system calibrated to the treatment isocenter. CT scans were acquired using a slice thickness of 1.25 mm. For each scan the phantom was positioned in the immobilizer and an attachment with IR-reflective spheres was added. Using the Brainscan 5.31 treatment planning system, the IR markers were localized and an isocenter placed on each fiducial. Plan information was exported to the Novalis Body computer. The phantom was initially positioned using the IR tracking system. X-ray images were obtained and an automatic 6-D bony fusion performed. Shifts calculated by the fusion were performed under guidance of the IR system. Port films were taken and the deviation between the center of the fiducial and the treatment isocenter was evaluated. **Results:** A total of 57 phantom setups were performed (19 for each anatomical location). The measured mean total system error magnitude was 0.73 mm with a standard deviation of 0.29 mm. The positioning accuracy for the lateral frontal fiducial was found to be slightly inferior to the other two with a mean error magnitude of 0.96 mm compared to 0.60 mm and 0.64 mm for cerebellar and mid-brain respectively. **Conclusion:** In all cases the radiosurgery accuracy requirements specified in AAPM Report #54 were met or exceeded. This system provides equivalent accuracy to conventional invasive frame based radiosurgery and can substantially improve both patient comfort and treatment planning workflow.

SU-FF-T-76

Accuracy of CT Based Volume Measurements Performed by Four Different Treatment-Planning Systems

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Purpose: To investigate the accuracy of volume measurements in phantoms with known volumes calculated by four radiation therapy treatment-planning systems from routine-clinic CT images and evaluate their overall performances. The methodology to improve the accuracy is proposed. **Method and Materials:** An ellipsoid mammosite was used as a phantom injected with 35, 45, 55, and 65cc of saline separately, and scanned by a multi-detector CT (GE, 4-Slice helical Scan, 1.25mm thickness, 512x512). The images were transferred to 4 treatment-planning systems: GE simulation workstation, ADAC Pinnacle, BrainLab and Varian VariSeed. Image windows & levels were adjusted to see the wall of the phantom and kept same in each system. ROIs of the phantom and central catheter were segmented in CT slices by automatic contour tool (unavailable in VarianSeed, manually contoured by a physicist). The total volume of each phantom was generated from 3D ROI stack by volume-calculating toolkits. The actual saline volume in each phantom was calculated by subtracting the catheter volume from the total phantom volume. To approach the true injected volume, dilation or erosion of phantom's ROIs was performed. **Results:** The average measured and the true volumes varied by -9.86%, -10.24%, -11.748%, -13.02% for the GE, Pinnacle, BrainLab, and VariSeed systems respectively. For 35cc phantom, if phantom ROIs were dilated by two pixels, the measured volume was approaching its true value. The difference between average measured and the true volumes decreased from -11.74% to -10.15 when phantom volumes increased from 35cc to 65cc **Conclusions:** Image windows & levels have the greatest impact on calculating accurate volumes. All planning systems underestimated the true volume of the phantoms by about 11%. This underestimation should be factored in the clinical settings when calculating Dose Volume Histograms especially for IMRT plans. Furthermore, two-pixel dilation could fill the gap between measurements and true volumes.

SU-FF-T-77

Accuracy of Gated IMRT Delivery On the Varian Linac Using the Real-Time Position Management System

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Purpose: To investigate the accuracy of gated IMRT delivery on a Varian linear accelerator equipped with the Realtime Position Management (RPM) camera and software. **Method and Materials:** A non-uniform dose distribution within a solid water phantom was contoured and planned with IMRT. A sinusoidally oscillating platform simulated superioinferior respiratory motion, and a reflecting block was placed on the surface of the platform to provide a "respiratory" signal to the RPM camera. First, the phantom was stationary while the platform served only to provide the respiratory signal. The respiratory period was 5 sec, and the treatment was delivered in phase-gated intervals of 6%, 10%, 25% and 50%. Second, the phantom was placed on the platform, with motion amplitude of 6 cm. Here, dose was delivered to the phantom during a small amplitude-defined interval at end-expiration, with periods 1.7 sec, 5.3 sec and 12.6 sec. Dose distributions were captured on film. **Results:** Dose profiles generally showed variation between configurations less than 2% the maximal dose, with shorter-interval delivery providing slightly less dose than longer-interval delivery. The only notable difference occurred for the phantom moving with respiratory period of 1.7 sec, where dose fluctuations of nearly 6% occurred at regions of high dose gradient in the direction of motion. It should be noted that the gating interval spanned 15% the respiratory cycle, implying the beam was delivered in only 1.7 x 0.15 = 0.25 sec intervals. **Conclusion:** Gated IMRT delivery provided dose distributions equivalent to ungated delivery to within clinically acceptable limits. This result held for significant motion amplitude, under a wide range of respiration frequencies and gating intervals. While discrepancies up to 6% arose at high gradient borders for configurations of extremely rapid motion and short beam-on time, these parameters are very unlikely to be seen in any clinical situation.

SU-FF-T-78

Accuracy of Patient Positioning Using BrainLab ExactTrac 4.5

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Purpose: To investigate the accuracy of the latest BrainLab treatment couch (ExactTrac 4.5) based on stereoscopic X-ray imaging and Infrared markers (IR). **Method and Materials:** BrainLab's ExactTrac treatment couch is being used for image guided intra-cranial and spinal radiosurgery. The system uses two oblique x-ray sources, embedded in the treatment room floor, coupled with ceiling mounted x-ray detection panels to acquire 2 stereoscopic digital images. ExactTrac also offers an IR tracking mechanism consisting of two IR cameras that identify IR external fiduciary markers fixed on the patient's skin. The IR system monitors patient position in 6 dimensions (6D, X, Y, Z, Roll, Yaw and Pitch). To evaluate the effects of CT slice thickness used for treatment planning on the positioning accuracy, we acquired 5 sets of CT images of a Rando phantom with slice thicknesses of 0.625, 1.25, 2.5, 3.7 and 5.0 mm using a GE helical scanner. Furthermore, we evaluated the reproducibility of phantom positioning using the IR tracking system due to random variability of the IR external markers placements within a 1 cm-diameter circle from their correct positions. **Results:** Our ExactTrac stereoscopic X-ray system positioned the phantom within 0.1 mm of the isocenter using either CT slice thicknesses of 0.625 or 1.25mm. Positional accuracy dropped to 0.5mm when CT slice thickness of 2.5 or 3.75 mm were used. The positional accuracy with CT slice thickness of 5.0 mm was within 2.5 mm. The average phantom positioning error due to misplacing the IR tracking markers was 0.79 mm.**Conclusion:** The patient tracking error of the new ExacTrac is within 0.25 mm when CT slice thickness of 1.25 mm or less is used for planning with stereoscopic x-ray imaging for positioning. The random placement of IR markers within a 1-cm diameter circle yielded a positional error of 0.8mm.

SU-FF-T-79

Accurate and Efficient Monte Carlo Dose Calculation for Electron Beams

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Purpose: To develop a Monte Carlo dose calculation engine for electron beams that is feasible for routine clinical treatment planning.
Method and Materials: The dose calculation engine consists of a description of the clinical beams and a dose calculation module. A 12-component multi-source model was used to characterize the phase-space of clinical beams. There are 6 components each for electrons and photons, corresponding to the 3 scrapers, x-jaws, y-jaws, and the direct component respectively. In addition, we have developed a method to account for the presence of an arbitrary shaped cutout by modifying the last component of the standard beam model. For the dose calculation module, implementation of the Super-Monte Carlo method accelerates the calculation by using electron and photon tracks pre-calculated in water to avoid the computationally intensive sampling processes. These tracks are replayed in the patient computer model as defined by CT. To account for inhomogeneities, the step size and scattering angle were adjusted according to the CT voxel values and material indexes. The dose calculation engine was verified by comparing with film measurements in several different geometries. **Results:** The results agreed with film measurements to within 2-5% percent both in homogeneous and heterogeneous phantoms. Our method is faster than the analog Monte Carlo calculation by a factor of 6 to 10 and is comparable in performance to a commercial system. The modified beam models for arbitrary cutouts can be derived in a few seconds. The disk storage for pre-calculated tracks is about 5.5 GB and 125 MB for the standard beam models.**Conclusion:** The developed Monte Carlo calculation engine is accurate and efficient. The disk space and computational time required are well within clinical acceptability. It is a highly promising dose calculation tool for routine clinical applications. This work supported in part by NCI grant P01-CA59017.

SU-FF-T-80

Acute Skin Toxicity for Woman Receiving Radiation for Breast Cancer in Relation to the Skin Dose

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Purpose: To investigate the relationship of clinically observed incidence and severity of acute skin toxicity and the skin dose received by the patient after intensity-modulated radiotherapy (IMRT) or conventional radiotherapy of breast cancer. **Method and Materials:** The study population consists of 133 women with early stage breast cancer treated with breast-conserving surgery and radiation therapy. Seventy three patients have been treated using IMRT and the rest 60 were treated using conventional techniques. The dose distributions were calculated retrospectively with the Monte Carlo method for all the patients. Beam phase space was used for dose calculation and the Monte Carlo results were validated by comparing with measurements. The smallest voxel size ($0.9\times0.9\times2.7mm^3$) converted from patient CT scan is used for Monte Carlo dose calculation. Dose to the skin epidermis which is less than 0.1mm thick can be estimated from the dose of the 0.9mm thick voxel based on the experience established from Monte Carlo simulations in a fine layered water phantom for beams with different incidence angle and ultra thin TLD measurements. **Results:** There was no desquamation in 42% of IMRT patients while 37% developed dry desquamation and 21% developed moist desquamation. The degree of desquamation was greater for conventional patients compared to IMRT patients - 52% grade 0, 10% grade 1 and 38% grade 2 ($p=0.001$). The IMRT dose distributions were more uniform compared with conventional treatments; 24% of the breast volume received dose more than 105% of the prescription dose for conventional treatment but only 7% for IMRT. Results show that a strong correlation exists between the area of skin receiving high dose and the severity of acute skin reaction. **Conclusion:** IMRT is associated with a decrease in severity of acute desquamation compared with conventional radiotherapy. Significant correlation is observed between the acute skin toxicity and the skin dose.

SU-FF-T-81

Adaptive Differencing Schemes with Parallel Computing for Detailed SN Solutions of a Co-60 Radiotherapy Unit

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Purpose: To apply deterministic techniques to provide a numerical solution for the 3-D integro-differential form of the Boltzmann transport equation using the discrete ordinates (S_N) method for a radiotherapy unit.
Method and Materials: Comparisons were made between deterministic and Monte Carlo simulations considering angular quadrature, spatial discretization (also spatial differencing), and cross section library selection. In order to assess these issues, we simulated the ^{60}Co beam from a standard *Eldorado* radiotherapy unit. In addition, we simulated the gantry, air gaps, and a water phantom. A 3-D spatial distribution was generated to yield a 24 'z-level' model of 150,000 fine mesh cells. To accurately compare our deterministic results with Monte Carlo, we considered an equivalent MCNP5 model with ENDF/B-VI cross-section data libraries and volumetric flux (F4) tallies along the central axis of the model. **Results:** Overall, deterministic S_N results yielded good agreement with Monte Carlo results within the Monte Carlo stochastic error for the reference case. At the same time, the parallel S_N model provided a full 3D-scalar flux distribution over the entire geometry within an acceptable running time. To accurately represent the radiation transport, a quadrature level of at least S_{24} was required with an added ordinate splitting refinement of 6 directions of interest. These results where obtained when the Directional Theta-Weighted (DTW) differencing scheme was locked for the regions with low density material (air regions), and the adaptive differencing scheme with upgrades up to the Exponential-Directional Weighted (EDW) differencing scheme was prescribed for higher density regions. **Conclusions:** The discrete ordinates (S_N) method provides a viable alternative to the Monte Carlo method for solving the Boltzmann transport equation. With the proper discretization, an adaptive differencing scheme, and suitable quadratures with ordinate splitting, the S_N method is a useful tool in determining the resulting radiation transport throughout a radiotherapy unit.

SU-FF-T-83

Algorithm for Optimizing Beam Angles in IMRT Treatment Planning

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Purpose: The goal of beam angle optimization in external radiation therapy treatment planning is to find field directions which shall result in an optimal treatment plan. In this work, a beam angle optimization algorithm to be used in Intensity Modulated Radiation Therapy (IMRT) treatment planning has been developed. **Method and Materials:** The plan optimality is defined by constraints set on the Dose-Volume Histogram (DVH) of the target(s) and of the critical organs. The same constraints may be applied both in beam angle and in beam profile (beamlet) optimization. In beam angle optimization, either a co-planar or a non-coplanar initial search space may be used. The search space is covered with a preset number of uniformly distributed fields. Thereafter, a few beamlet optimization iterations are calculated in order to produce optimal beam profiles. Each field is then removed from the plan, and the corresponding value of the objective function is calculated. The fields with a low importance value are thereafter removed. The process is continued until the desired number of fields in the plan has been reached. **Results:** The optimized plans have been compared with equispaced beams, class solution –based plans and manually made plans. Beam angle optimization has been found to decrease the OF value typically to 20-80 % of the original value calculated with reference plans. The improvement has been clearly visible also in the shape of the DVH curves. The algorithm has been designed to execute fast (less than 30 minutes) in order to be applicable in routine use for patient-specific planning. **Conclusion:** The new beam angle optimization algorithm has been able to produce IMRT plans with superior quality to class solution or manually made plans. **Conflict of Interest:** This work has been funded by Varian Medical Systems Inc.

SU-FF-T-84

An Alternative Calibration Method for Solid Modulator IMRT

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Purpose: Solid compensators for intensity modulation have become very popular. The purpose of this presentation is to investigate the differences, for three separate measuring tools, in calibration using open fields and calibration with an attenuating material in the beam. Doses for both open fields and attenuated fields were confirmed using farmer chamber measurements. It is crucial to understand the differences in detector response between open and attenuated beams in order to make measurements of modulator based IMRT more accurate. **Method and Materials:** Three different types of measuring devices were investigated for this analysis: GafChromic EBT film, Kodak EDR2 film, and the SunNuclear Mapcheck system, each compared against ion chamber readings. Each system was irradiated with a 4 x 4 cm^2 field size for various doses. The same dose measurements were made for each system with a 3cm brass modulator in the wedge slot. After the films were scanned, light transmission value readings were obtained. For the Sun Nuclear Mapcheck system, direct readings of the central axis diode were obtained, again using the open field and the brass modulator. Measurements were made with a Farmer chamber to confirm that the doses from open and attenuated fields were equal. **Results:** The percent error differences in measurements using open versus compensated fields for EBT, EDR2, and MapCheck are 0.63%, 2.88%, and 1.01% respectively, while the Farmer chamber was only 0.07%. **Conclusion:** The small value in the Farmer chamber indicated that our calculation was accurate. The EDR2 film showed a high difference in readings compared to that for the EBT film and the MapCheck system. Due to these differences we conclude that one should use a modulator in the beam while calibrating a system for the use of modulator based IMRT. **Conflict of Interest:** Chris Warner works for .decimal.

SU-FF-T-85

An Alternative Technique for Breast Tumor Bed Boost: MammoSite HDR Brachytherapy

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Purpose: The use of the MammoSite applicator as an alternative technique for delivering the tumor bed boost is analyzed. The equivalent fraction size in MammoSite boost is estimated based on the LQ model. **Method and Materials**: 42 patients treated with MammoSite brachytherapy were investigated. Two electron fields were setup for each patient: based on the scar and based on the seroma shown on the pre-scan CT. The electron energy was determined depending on maximum depth of the tumor bed on the CT scan. Isodose distributions were generated for each electron plan and compared with those from the MammoSite plan. Employing the concept of BED and EUD, the fraction dose for the MammoSite boost (2 fractions, bid. α/β=10Gy, Tp=15 days, α=0.3 cGy) was estimated to match the electron treatment scheme (10Gy in 5 fractions). The late toxicity was estimated as well. **Results**: V100 for the electron boost plan based on the scar were 39.7% and 69.2% based on the seroma location. The coverage was improved to 92.1% when the MammoSite applicator was used. There were no statistically significant differences for the V50 of normal breast tissue, lung V30, and maximum dose of the heart between the electron plan based on the seroma location and MammoSite boost plan. Contralateral breast received higher dose for the MammoSite plan. The estimated fraction size with and without considering the tumor proliferation were 3.04~3.15Gy×2 fraction and 3.21~3.32Gy×2 fraction, respectively. The late toxicity based on the calculated prescribed dose was comparable between the Mammosite and electron boost. **Conclusion**: Applying the MammoSite brachytherapy to deliver a boost dose to the primary tumor bed appears to be more precise relative to the conventional electron boost technique. The benefit of dose better localized to the target is expected to result in better local control.

SU-FF-T-86

An Automatic Field-Matching Technique to Treat Multiple Targets with a Single IMRT Plan

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Purpose: To treat multiple targets with a single IMRT plan with automatic field matching and different sets of angles for each target. In the treatment of head-and-neck (HN) malignancies with IMRT for example, the traditional approach is to deliver 7-9 IMRT fields matched with a static half-beam blocked supraclavicular field. However, significant cold and hot spots are frequently observed near the field junction. We have developed a technique to generate a single IMRT plan that eliminates the need for beam matching and reduces excess irradiation of normal tissue. **Method and Materials:** Direct aperture optimization (DAO) [1, 2] is an inverse planning technique where the MLC delivery constraints are incorporated into the plan optimization. By defining the initial apertures prior to optimization, the IMRT fields are limited in the search space for the MLC leaves, which served as a seeding solution. The fields are restricted so as to prevent them from exceeding the beam's eye view of their assigned targets. With this approach a single IMRT plan can be generated for multiple targets with different sets of gantry angles and automatic field matching. **Results:** Using DAO and defining the initial MLC aperture technique can produce a single IMRT plan for multiple targets without field matching. In the case of HN, 7 to 9 fields were assigned to the primary tumor, upper neck, and a portion of the lower neck nodes. An anterior and a posterior field were assigned to the mediastinum and a portion of the lower neck nodes. The resulting single isocenter IMRT plans were delivered without the need to junction fields. **Conclusions:** By using different beam arrangements, a single IMRT HN plan can be generated to treat multiple targets with needing to match fields.

SU-FF-T-87

An Empirical Method for the Determination of Wall Perturbation Factors for Parallel-Plate Chambers in High Energy Electron Beams

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Purpose: The National Physical Laboratory operates an absorbed dose calibration service for therapy-level electron beam ionization chambers. The service is based on a primary standard graphite calorimeter and uses cavity theory to obtain absorbed dose to water calibration coefficients. The dose transfer process requires knowledge of the ratio of perturbation factors in graphite and water phantoms for the NACP reference ionization chamber type used. A value of unity at present is assumed for this perturbation ratio but data published in recent years indicates that this assumption may be in error by as much as 1%. **Method and Materials:** Using chamber backscatter data an empirical model was developed to calculate the perturbation due to the rear wall, p_{wall}, of a well-guarded ion chamber in a high-energy electron beam. The overall uncertainty in this method is estimated to be 0.22%, which is the lowest reported to date. **Results:** The model reproduces measured data at the 0.1% level or better and indicates that the NACP ion chamber has a non-zero perturbation factor in electron beams due to backscatter from the rear wall. The effect is small (< 0.5%) at high energies (R_{50} > 4 cm, E_0 > 10 MeV) but becomes large at low energies – up to 1.0% at E_0 = 4 MeV (R_{50} = 1.2 cm). The model indicates that there is a non-zero correction for the NACP chamber in both a graphite and water phantom and that material adjacent to the air cavity has a significant effect on the measured ionization. **Conclusion:** These values are consistent with previous measurements and recent Monte Carlo calculations. The model is simple to apply and could be used in the design of ion chambers and also in the estimation of corrections for non-homogeneous systems, especially in the absence of accurate Monte-Carlo simulations.

SU-FF-T-88

An Experimental Evaluation of the Impact of Setup Uncertainty On Dose Near the Surface for IMRT Plans Where the Skin Is Considered a Sensitive Structure and Is Excluded From the PTV

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Purpose: (1) To investigate the impact of setup uncertainty on doses near the surface for IMRT plans where the skin is considered a sensitive structure and is excluded from the PTV. (2) To evaluate the impact of PTV design (how close to the skin the PTV is allowed) and number of gantry angles. **Method and Materials:** Effects of setup uncertainty were investigated experimentally using a semi-cylindrical phantom with MOSFET dosimeters positioned at depths of 3, 6, 9 and 12mm. A CT image was taken of the phantom, and a node-like CTV was drawn near the surface. Two PTVs were created by uniformly expanding the CTV by 5mm, and then pulling back 3 and 5mm from the body contour (PTV(3mm) and PTV(5mm), respectively). A 2mm skin structure was contoured. Seven and nine-field IMRT plans were created using Eclipse for each PTV with the following guidelines: 99% of PTV volume to receive 90-93% of prescribed dose, maximum 105% hotspot, and minimize dose to skin structure. The phantom was then positioned at isocenter, the planned treatments delivered using a Varian 21Ex, and doses delivered to the build-up region were measured. Setup uncertainty was simulated by shifting the phantom laterally in a range ±5mm, and the experiment repeated. **Results:** The number of beams did not significantly affect the results. For PTV(5mm), setup errors of 3 and 5mm reduced dose at 6mm depth by an average of 8% and 17%, respectively. For PTV(3mm), this was reduced to 4% and 12%, respectively. Corresponding numbers for 3mm depth were 8% and 12% for PTV(5mm), and 4% and 9% for PTV(3mm). **Conclusion:** To avoid daily dose to the surface nodes being reduced by more than 5%, the PTV should not be pulled back more than 3mm from the body contour, and setup uncertainty should be kept below 3mm.

SU-FF-T-89

An Exploration of New Formulations for PRESAGETM 3D Dosimetry

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Purpose: Presage is a new radiochromic material with substantial promise as a practical and convenient 3D dosimeter. Here we investigate new formulations of PRESAGE^{TM} to determine formulations that have high sensitivity, high stability, and/or are amenable to repeat measurements. **Method and Materials:** PRESAGE^{TM} formulations were manufactured in 2 mL glass vial samples and were irradiated in a 6MV photon beam to a dose of 5 Gy. Fifteen formulations were studied, eight of which were variations containing leucomalachite green (LMG) and seven variations containing leuco crystal violet (LCV). The transmission spectra (500-700 nm) were measured in a spectrophotometer for each sample pre-irradiation and then approximately one hour post-irradiation. Subsequent spectrum acquisitions were recorded at 2, 24, 48, and 72 hours post-irradiation to ascertain the stability of optical density changes. **Results:** Overall, the LCV formulations show greater sensitivity than the formulations containing LMG. The most promising LCV formulations exhibit a 15 – 33 % increase in post-irradiation absorption relative to pre-irradiation. The LCV formulations had minimal post-irradiation color bleaching from 2 to 72 hours, while the LMG formulations varied widely in stability post-irradiation. A number of the LMG samples returned to their pre-irradiation optical density, suggesting the possibility of a formulation which could be reusable. In addition, two of the formulations which contained polymeric acrylates along with the leuco dyes increased transmission relative to pre-irradiation, illustrating the intriguing potential of an 'inverse radiochromic dosimeter' (i.e. a dosimeter that becomes clearer after irradiation). **Conclusions:** Absorption changes post-irradiation identified LCV formulations with the initial response and stability for application in 3D dosimetry. In addition, LMG formulations were identified that may permit the unique potential for 'inverse radiochromic dosimetry' and reusability.

SU-FF-T-90

An Improved Irradiation Setup for An Accurate Measurement of the Dose Rate Constant of Low-Energy Brachytherapy Sources Using Micro-TLD Cubes

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Purpose: To develop an improved irradiation setup for the measurement of dose-rate-constant for interstitial brachytherapy sources using micro-TLD cubes by placing a TLD cube at the mid-point of two sources of nearly equal air kerma strength separated by a distance of 2 cm in a water equivalent solid phantom. **Method and Materials:** The impact of geometric uncertainties associated with micro-TLD cubes on measuring the dose-rate-constant of low-energy brachytherapy sources was investigated quantitatively. Integral dose deposited to the volume occupied by a TLD cube in water was calculated by using the Berger formula for the conventional one-source and the proposed two-source irradiation setups. The effects of TLD size, shape-asymmetry (due to mechanical damage and manufacturing defect), and positioning uncertainty on the dose measured by TLD was quantified by comparing the integral TLD dose to expected point-dose at the measurement point. **Results:** For a perfect TLD cube centered at the reference point, the integral dose to TLD was nearly identical to the expected point-dose, independent of TLD orientations. Displacements of TLD by 0.1 to 0.5 mm in the source-TLD direction resulted in dose errors of 2.3 to 10% in the one-source setup and 0.1 to 1% in the two-source setup. The dose errors were < 1% when the displacements of < 0.5 mm was in the perpendicular direction for both setups. The shape asymmetry measured by volume deficit produced similar dose errors, from 2.5% to over 9%, in both setups for volume deficits of 3 to 10%. **Conclusion:** To keep geometry-induced uncertainty in dose-rate-constant measurement < 2%, the TLD cube must have 1) nearly perfect symmetry with volume deficits < 2%, 2) positional uncertainty < 0.1 mm in source-TLD direction and < 0.5 mm in perpendicular direction. The requirement for TLD positioning is greatly reduced in the proposed two-source experimental setup.

SU-FF-T-91

An IMRT Planning Technique for Head-And-Neck Cancers That Utilizes Direct Aperture Optimization

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Purpose: IMRT can play an important role in the irradiation of head and neck tumors traditionally treated by lateral fields matched with an anterior supraclivicular field. However, due to the complex PTV geometry, these IMRT plans result in large numbers of segments leading to inefficient deliveries. We have developed an alternative IMRT planning technique utilizing Direct Aperture Optimization (DAO) to streamline the planning process and provide significant efficiency gains. **Method and Materials:** The process begins with the placement of traditional 3D conformal fields (laterals and anerior superclavicular). Next, the dose is calculated with this beam arrangement. The 90% isodose line is converted into a PTV with surrounding critical structures (e.g. spinal cord, parotid glands, posterior medial neck region) excluded from the PTV definition. The resulting PTV serves as the target for IMRT planning. For our planning technique, we have used the DAO algorithm in the Prowess Panther planning system. DAO plans generally result in significantly fewer segments as compared with those generated by traditional IMRT planning techniques. This is of critical importance since traditional IMRT plans for these cases have excessively long treatment times. Using DAO allows practical treatment times without sacrificing plan quality. **Results:** Fifteen patients were planned and treated with this technique. Seven equispaced beams were used in each. The objectives were PTV dose conformity and low dose to any avoidance regions. The spinal cord limit was 40Gy. For the DAO plans, treatment times ranged from 9 to 17 minutes on an Elekta SL20 acclerator. For corresponding plans produced using Pinnacle^3, treatment times ranged from 30 to 45 minutes. **Conclusions:** An IMRT treatment technique for head and neck cancer has been devised. This technique removes field matching and allows the initial 50Gy to be delivered with a single plan. Using DAO provides significant reductions in treatment times.

SU-FF-T-92

An Investigation of the Effect of IMRTwith Large Jaw Defined Back-Up Fields On the Accuracy of Dose Calculations

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Purpose: To investigate the effect of IMRT with large photon-jaw defined back-up fields on the accuracy of dose calculations by analyzing the deviation between calculated and measured dose, DV, for 19 IMRT cases with various jaw defined field sizes. **Method and Materials:** Suppose that D_c is the point dose calculated from a Pinnacle treatment planning system (TPS), and D_m is the dose measured at the same point in IMRT-QA. The DV is defined as $(D_m-D_c)/D_m$. Each IMRT case in this work had two PTVs, PTV1 and PTV2. For every case, the average equivalent field size (AEFS) of jaw defined fields for PTV1 was considerably larger (at least 3.5 cm larger) than that for PTV2 of the same case. The point at which the dose was measured and calculated was the same for PTV1 and PTV2 for each case. We compared the DV for PTV1 with that for PTV2. The beam energy used was 10 or 18-MV. A 0.3cc ion chamber placed in solid water was used for measurements. **Results:** The AEFS of jaw defined fields for PTV1 ranged from 12.8 to 16.3 cm, and for PTV2 from 7.2 to 9.9 cm. The DV for PTV1 was from 2.7 to 8.9%, and for PTV2 from -2.1 to 3.3%. For 17 of 19 cases, the DV for PTV1 was much larger than that for PTV2. The average DV for PTV1 and PTV2 were 6.1 and 1.8% respectively. **Conclusion:** The results indicate that significant deviation between calculated and measured dose could be associated with IMRT using large jaw defined fields. It is possibly because the TPS doesn't fully account for radiation transmission and leakage through MLC and interleaf for large jaw defined fields. We believe that, to increase dose accuracy, MU corrections are necessary for IMRT with large jaw defined fields.

SU-FF-T-93

Analysis of the Impact of Skull Scaling Deviations in Gamma Knife Radiosurgery

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Purpose: To investigate the impact of variations in skull scaling measurements in Gamma Knife radiosurgery. **Method and Materials:** We developed an in-house planning algorithm able to calculate the boundary of the skull directly from an image set. We imported 11 patient plans and obtained the skull contours from the image set. We then manually replicated GammaPlan's skull scaling interpolation directly into our algorithm, and noted the change in times and isodose line distribution produced by such changes. **Results:** Dipstick measurements on average deviated from our skull measurements on average 8 mm. Prescription isodose lines were not visibly affected by the differences in skull scaling. Time calculations were affected by skull scaling differences; in multi-shot plans, shot times differed from 0.6% to 2.9%. Prescription isodose lines did not shift significantly despite significant differences in skull scaling. Differences were similar regardless of lesion location. For single shots, times differed depending on the proximity of the shot to large differences in skull boundary; thus shots placed in the frontal region demonstrated discrepancies of approximately 5%, whereas shots placed superiorly (where the interpolation tends to be successful) and centrally (far from skull boundaries) showed differences of less than 1%. **Conclusion:** For most lesions, skull scaling will not affect the treatment times by more than 3%. Single shots placed near a defective skull interpolation will be the most strongly affected, with discrepancies in time calculations of 5%. It is important to consider the quality of the skull interpolation surrounding the lesion to be treated, as the quality of the treatment could be impacted.

SU-FF-T-94

Analytical Calculations of Dosimetry Data for a 6-MV Narrow Radiosurgery Beam with Cones

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Purpose: To analytically derive narrow beam dosimetry data for a 6 MV radiosurgery beam with cones from broad beam measurements. **Method and Materials:** currently radiosurgery dosimetry calculation is commonly done using a radiosugery treatment planning system. Such a planning system is typically commissioned using output factors, TMR, and off-axis ratio measured in water for narrow beams. The experimental measurements in water for small radiosurgery beams are difficult and with large uncertainty due to lack of lateral electronic equilibrium and finite detector size. In this work, an analytical model was used to calculate the cone factors, TMR, and off-axis ratio (OAR) for various cone sizes for a 6 MV radiosurgery unit. The model is parameterized with the measured broad beam cax beam data where lateral dose equilibrium exists and accurate measurement can be performed without much of difficulties. The calculated results were benchmarked with the experimental measurements. The cone size ranged from 4 mm to 20 mm in diameter in this study. **Results:** Compared the calculated dosimetry data with those from measurements, the agreement for cone factor was within 1 %, and within 4 %for TMR beyond d_{max}. The agreements for OAR are within typical experiment uncertainties. **Conclusion:** The analytical method described here can be used to calculate narrow cone beam dosimetry data in place of the arduous in-water narrow beam measurements. Alternatively, it can be used to validate narrow beam dosimetry measurements if the direct measurements are prefered.

SU-FF-T-95

Analytical Neutron Shielding Calculations

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Purpose: The primary purpose of this study is to estimate wall thicknesses that will limit instantaneous dose equivalent rates outside the shielding walls to less than 0.02 mSv hr-1 in areas that may be occupied by non-designated workers. The other primary design considerations are the integrated annual dose equivalent and the integrated shift dose equivalent. These integrated dose equivalents have been calculated based on a maximum workload. The design aim has been to achieve levels that are in compliance with the University of Pennsylvania's ALARA commitment and NCRP standards. **Material and Methods:** In proton therapy, energies at and below 250 MeV produce neutrons when the proton beam is stopped in matter. Hence, the problem of proton shielding is a neutron shielding problem. Experimental data of various cross-sections for neutron production by energetic protons across the proton energy range of interest (~10-250 MeV) is not widely available. In order to predict the neutron spectra produced by a 250 MeV proton we used the Monte Carlo code GEANT4 v6.2 to simulate the protons passing through various targets (water, iron, carbon and tungsten) and recording the number of neutrons captured in one steradian. **Results:** The output of the shielding calculation gives (1) the instantaneous dose equivalent rate, (2) integrated weekly dose equivalent and (3) integrated annual dose equivalent at various points of interest for a defined shielding thickness. These points are sources of maximum dose rates around and inside the vault. **Conclusion:** We have used analytical techniques and Monte Carlo simulations to investigate neutron shielding considerations for a proposed proton therapy facility that will be situated on the University of Pennsylvania campus. These preliminary results give a good indication of what dose is expected at selected points inside and outside the treatment rooms and around the accelerator vault.

SU-FF-T-96

Analyzing Tertiary Multileaf Collimators Position Effect On the Dose Distribution in Irradiated Field Edge

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Purpose: To study the varying of dose distribution at the irradiated field edge (IFE) affected by the relative position between jaw and MLC setting. **Method and Materials:** Varian 21EX linear accelerator with 80 MLC was used for this study. The dose distribution was measured with a 2D-array Seven29 (PTW) ion chamber with 6 and 18 MV photon beam and field sizes (FS) 5x6, 10x10, 15x16 and 20x20cm^2. Ion chamber array was set perpendicular to the central axis beam and placed at 100 cm SAD at Dmax. Dmax was built with a solid water phantom. Measurements were taken at following four field setting: (1) MLC aligned up with jaw, (2) MLC 1cm larger than the jaw setting, and (3) MLC 2cm larger than the jaw setting, and (4) MLC fully retracted. Dose comparison was done between the field setting (1) and the others at x-axis and y-axis IFE separately. To minimize the measurement device inaccuracy, dose was measured at 0º and 90º collimator angles with FS 10x10cm^2 for the verification. To limit the setup error, each set data was measured at same setup. **Results:** There was not significant dose different observed from x-axis direction. However, there

were 2.8, 4.3, 6.3 and 7% lower dose observed from y-axis direction with four measured FS from 18 MV beam, respectively. A similar result was observed from 6 MV beam. The difference amount other three settings was less than 1%. **Conclusions:** Relative jaw and MLC location affects a dose distribution significant at y-axis IFE and this effect increased with the off central axis distance. We recommended that for a linac commissioning with jaws alone, when a tertiary MLC is used to shape an irradiated field, a 1cm extra distance should be provide from MLC at y-axis direction to avoid the low dose at IFE.

SU-FF-T-97

Application of a Rotatable Isocentric Phantom for Determining Geometric Errors in Gantry Rotation of a Complete LINAC System Including EPID and OBI

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Purpose: With the onset of on-board-imaging (OBI) and 2D-2D matching programs to determine table shifts in IGRT, QA tests are needed to assess the accuracy of these shifts. Hence, the purpose of this study was to investigate geometric inaccuracies in that could occur within a LINAC with EPID and OBI due to gravity effects when the gantry is rotated. **Method and Materials:** A rotatable isocentric phantom (Modus Medical Devices) was aligned to the lasers in our CT simulator. CT scans with 1mm slice thicknesses were transferred to the Eclipse TPS. DRR's were generated and exported into our IMPAC R&V system. The phantom was then aligned to the lasers in the Linac room. A Varian iX LINAC with EPID and OBI was used to obtained orthogonal pairs of images with the gantry set to 0°, 90°, 180°, and 270°. For each image the phantom was rotated such that its top surface was parallel to the imaging detector. The Varian 2D-2D image matching program on the OBI computer was used to determine the geometric inaccuracies. **Results:** The initial set up of the phantom immediately revealed a misalignment of 2.5mm in the external lasers in the CT simulator. In addition, the CT scanner table sagged as much as 3.9 cm as it entered and passed the bore with an 68kg on the table. Imaging on the Linac with the MV or kV source at 0° (top) showed images that were perfectly aligned. However, when the kV source and detector was used at 270° or 90°, the images were up to 2mm off due to gravity effects. **Conclusions:** A technique was developed to determine the geometric inaccuracies found in a LINAC with EPID and OBI. Equipment sag showed that table shifts of less than 2mm may not be real or needed.

SU-FF-T-98

Application of DAVID, a Multi-Wire Ionisation Chamber for in Vivo-Verification of IMRT and Conformal Dose Distributions

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Purpose: In this work we present first clinical results obtained with the DAVID chamber. **Methods and Material:** The DAVID system (PTW Freiburg, Germany) is a flat, translucent multi-wire ionization chamber for daily *in-vivo* verification of IMRT beams. It is placed in the accessory holder of the linear accelerator. Each detection wire of the chamber is positioned exactly in the projection line of two opposing leafs of the MLC. The signal of each detection wire is proportional to the line integral of the ionization density along this wire, therefore it is directly proportional to the opening of the associated leaf pair. The number of measurement channels equals the number of leaf pairs. The sum of all wire signals is a measure of the dose-area product of the transmitted photon beam and of the total radiant energy administered to the patient. **Results:** After a successful dosimetric verification of an IMRT plan, the values measured by the DAVID system are stored as reference values. During daily treatment the signals are re-measured and compared to the reference values. In case of a deviation beyond a threshold a warning occurs. Because the DAVID system operates as an ionization chamber, disadvantages which might be observed in other devices, such as aging, are not to be expected. Furthermore, the influences on the beam characteristics are negligible.**Conclusion:** Clinical examples demonstrate that the DAVID system is a relevant tool to improve the reliability of IMRT treatments. **Conflict of Interest:** The DAVID system was developed in cooperation with PTW-Freiburg, Germany.

SU-FF-T-99

Application of Dose Uncertainty Model for Plan Evaluation

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Purpose: To provide the applications of dose uncertainty model for intensity-modulated radiation therapy (IMRT) plan evaluation. **Method and Materials:** The dose uncertainty in radiation therapy is proportional to the product of dose gradient and spatial displacement (space-oriented uncertainty) and inversely proportional to dose level (non-space-oriented uncertainty). Since both dose uncertainties are assumed independent, the total dose uncertainty is their square root of quadratic sum ($\sigma(\vec{r}) = \sqrt{\sigma_s(\vec{r})^2 + \sigma_{ns}(r)^2}$). If the dose distribution consists of multiple fields, the total uncertainty is the square root of quadratic sum of dose uncertainties of all beam segments. To apply the uncertainty model to IMRT plan evaluation, three patients were selected and three different step-and-shoot IMRT plans for each patient were made with 95% of planning target volume (PTV) covered by prescribed dose (180 cGy) using Philips Pinnacle[3]. Three-dimensional (3-D) dose uncertainty distributions were calculated with 1% relative dose uncertainty at the prescribed dose level and 1 mm spatial displacement along each Cartesian axis as one standard deviations assuming Gaussian distribution. The uncertainty distributions added to and subtracted from the calculated dose distribution were employed to make isodose lines with 95% confidence interval (1.96σ). The plans with the isodose lines of each patient were compared to choose more preferable plan. In addition, the uncertainty-volume-histogram (UVH) was developed as an additional tool for plan evaluation. **Results:** By observing possible overdose and underdose regions within PTV with 95% confidence level, better plan evaluation was accomplished. Moreover, the plans that might bring less possible damage to organs at risk could be selected by considering both the dose bounds and UVHs of each organ. **Conclusion:** The 95% isodose bound and UVH are new useful tools for better IMRT plan evaluation. The uncertainty model can bring a new paradigm of plan evaluation by avoiding the choice of a plan of high risk.

SU-FF-T-100

Application of Statistical Process Control to IMRT Quality Assurance

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Purpose: An investigation was undertaken to determine the efficacy of the application of statistical process control (SPC) methods to the quality assurance measurements for individual patients prior to the application of intensity-modulated radiation therapy (IMRT). **Method and Materials**: SPC is a quality control methodology developed by industrial engineers. IMRT treatments were delivered using 6MV and 18MV x-ray beams produced by a medical linear accelerator equipped with a 120-leaf multi-leaf collimator. Treatment plans for delivering IMRT were computed for fifteen patients using a commercial treatment planning system. A "phantom plan" was calculated for each patient. To compute the "phantom plan", the patient's virtual simulation CT data set was replaced by a CT scan of an ellipsoidal water equivalent phantom. The dose distribution was recomputed using the machine parameters that had been computed for the patient. Measurements of dose were made using a calibrated 0.2 cc Farmer-type ionization chamber in the water equivalent phantom. The dose was delivered using the same computer files that were to be used for treating the patient, and exactly the same medical linear accelerator parameters. The dose measured at points in the phantom was compared with the dose computed at the same points in the "phantom plan". The dose differences were analyzed using the methods of SPC. For each patient a sample size of 2 was used. SPC Charts were constructed for the remaining ten patient cases employing the control limits derived from the first five cases. Additional studies of the performance of SPC were made using measurements with controlled errors introduced into the treatment delivery. **Results**: The patient cases remained in statistical process control. Addition measurement demonstrated that the SPC graphs detected intentionally introduced errors. **Conclusion**: Statistical Process Control is a practical technique for analyzing the patient specific quality assurance data for IMRT.

SU-FF-T-101

Application of the Post-Processing Dose Tool (PPD) to Dosimetrically Compare Gamma Knife and Hi Art Tomotherapy

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Purpose: To develop a tool that enables us to process the dose matrix generated by the same or different radiation treatment planning system. **Method and Materials:** A Matlab tool was developed in order to post-process the dose matrix generated from different treatment planning systems. Currently, the tool can import the dose matrix from Pinnacle[3], Tomotherapy, Nomos Corvus and gamma knife planning computers. Tumor contours can also be imported. Using the tool one can calculate region-of-interest dose statistics, dose volume histograms (DVH), 2D dose maps, 3D dose maps, effective uniform dose (EUD), biological uniform dose (BUD), and dose profiles. The software tool can produce a comprehensive report that includes all the calculation. The software has been used to facilitate a comparison study between Tomotherapy and Gamma Knife for radiosurgical cases. The conformality index, defined as the ratio of the prescribed dose divided by target volume, was used to evaluate the treatment plans. Maximum dose, minimum dose, means dose, DVH and treatment time were also parameters used in the comparison. **Results:** Five gamma knife patients have been selected as candidates for the dose comparison between tomotherapy and gamma knife. All five patients had single brain lesions. Results show that tomotherapy can achieve the same DVH with higher dose conformality as compared to GK. However, the treatment volume of the lower dose lines (<10 Gy) is higher than gamma knife. **Conclusion:** A Matlab tool has been developed for post-processing dose matrices generated by different treatment planning systems. The tool has been applied on comparison of the radio surgery cases between tomotherapy and gamma knife. The comparison results show that tomotherapy can deliver radio surgical precision and achieve the same results as gamma knife considering conformality index, maximum dose, minimum dose and mean dose in the tumor.

SU-FF-T-102

Application of the Quality Index Methodology for Dosimetric Verification of Build-Up Effect Beyond Air-Tissue Interface in Treatment Planning System Algorithms

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Purpose: We have developed and applied a methodology based on quality index (QI) to assess the accuracy of calculations performed on a number of commercial treatment planning systems (TPS) for the case of build-up effect beyond air-tissue interfaces. This methodology requires the preliminary constitution of a "reference data set", obtained experimentally, where correction factors (CF) were calculated as the ratios of the ionization at a depth d beyond the air-tissue interface to the ionization at the same geometrical point for the reference configuration and for the same number of monitor units. Material and Methods: CFs were obtained from measurements in a phantom that consisted of polystyrene slabs with a 10 cm air-gap between them. Measurements were performed with a plane parallel ionization chamber at different depths beyond the distal air-polystyrene interface. They have been repeated with and without the air-gap at constant source-detector distance, for a 5x5 cm2 field and for photon energies ranging from 4MV to 23MV and the respective Monte Carlo calculations have been performed the same phantom set-up. **Results:** A number of commercial TPS algorithms were tested: users computed CF using basic beam data from their accelerators and these were compared to reference CF for the corresponding QI. Considering that the error in the determination of CF for all beam energies tested should not exceed 6%, at the tested depths only one algorithm calculated CF within this error. The rest of the algorithms overestimated or underestimated CF in the build-up region. At depth where electronic equilibrium is achieved, results were acceptable for all algorithms. **Conclusions:** A test that can be easily performed has been designed to validate the calculation algorithm of a TPS for the build-up effect, using the QI of the incident beam.

SU-FF-T-103

Application of the Strydom Analytical Model to the Remote Monitoring of Electron Beam Dosimetry Parameters by Thermoluminescent Dosimetry

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Purpose: To provide a practical methodology and a reference percentage depth dose (PDD) data set for streamlining the Radiation Dosimetry Services (RDS) TLD verification of electron beam output and PDD. **Methods and Materials:** PDD data from 29 Siemens Primus and 19 Varian Clinac 21EX accelerators were retrieved from the databases of RDS and the Radiological Physics Center (RPC) and were simultaneously fitted to the nonlinear Strydom analytical model. The NLIN (SAS 9.1) procedure was used to fit the models. The PDD data sets used in the models were independently measured by many physicists from many institutions and verified by TLD and RPC onsite measurements. The resulting reference PDD data sets were incorporated into the RDS TLD analysis software for electron beam monitoring. **Results:** The parameters of the model were estimated for 5 to 21 MeV electron beams for Siemens and Varian machines. Individual PDD data fell within ± 1.5 mm of the reference PDD data for all depths for all beams analyzed. The curves exhibited similar shapes and were found to agree within ± 1.0 mm at all depths when all the curves for a particular energy were made to coincide at the depth of 50%. The validated reference model's predictions shows good agreement with other published results. **Conclusions:** The shape of the PDD curves was found to depend only on beam energy, and was independent of model for newer machines. These results allowed RDS to streamline its process of evaluating TLD results for electron beams and to acquire additional information about an institution's PDD data to facilitate the identification of problems. The reference PDD data sets can serve as a resource to the medical physics community. **This work was supported by PHS grant CA 10953 awarded by the NCI, DHHS and Radiation Dosimetry Services.**

SU-FF-T-104

Arc Sequencing – An Inverse Planning Technique for Intensity Modulated Arc Therapy

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Purpose: Intensity modulated arc therapy (IMAT) is a rotational approach to IMRT in which the leaves of the multileaf collimator move continuously during arced beam delivery. Overlapping arcs are used to deliver optimized intensity patterns from each beam direction. Despite the promising nature of IMAT, its potential has gone largely unrealized due to a lack of robust inverse planning tools. To address this, we have developed an IMAT arc sequencing algorithm that translates optimized intensity maps into deliverable IMAT plans. **Material and Methods:** The arc-sequencing algorithm uses simulated annealing to simultaneously optimize the aperture shapes and weights throughout each arc. The sequencer enforces the delivery constraints while minimizing the discrepancies between the optimized and sequenced intensity maps. The performance of the arc sequencer has been tested for ten patient cases. An IMRT plan was developed for each case using the Pinnacle[3] treatment planning system, and the arc sequencer translated the optimized plans into deliverable IMAT plans. **Results:** Ten IMAT patient plans were developed covering the following sites: 3 prostate, 3 brain, 2 head-and-neck, 1 lung, and 1 pancreas. Seven coplanar IMAT plans were created using an average of 4.6 arcs and 685 monitor units. Additionally, three noncoplanar plans were created using an average of 16 arcs and 498 monitor units. The results demonstrate that efficient IMAT delivery plans can be developed that combine the dosimetric advantages of arc therapy with the dose painting capabilities of IMRT. Only modest degradation was seen between the pre and post sequenced plans. Plan accuracy was verified using Monte Carlo dose calculations with each arc approximated as static beams separated by two degrees. An average sequencing time of under 25 minutes was observed. **Conclusions:** An arc-sequencing algorithm has been developed that can serve as the first robust inverse planning tool for IMAT.

SU-FF-T-105

Assessing Influence of Motion in Non-Gated and Gated DMLC-IMRT Delivery Using Measured Fluence Fields for Dose Reconstruction

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Purpose: Recalculating dose distributions using measured IMRT fluence fields imported into the treatment planning system (TPS) to evaluate breathing synchronized irradiation. **Method and Materials:** DMLC-IMRT fluence patterns acquired on radiographic film, generated in non-gated and gated mode, have been imported into the TPS. The effect of dose blurring and the efficacy of a breathing synchronized irradiation technique have been evaluated using radiographic film mounted to a phantom simulating a breathing pattern of 16 cycles/min and 4cm amplitude. Two situations have been investigated: (a) A spherical lesion located close to the diaphragm assessing the influence of motion on the dose to the target volume and the gastro-intestinal tract. (b) A mediastinal lesion requiring complicated fluence patterns. **Results:** Disturbed dose reconstructions have been observed in case of the non-gated delivery with the phantom in motion (both orthogonal and parallel to the leaf direction), whereas the measurements from the static and gated deliveries showed good agreement with the theoretical dose distribution. These findings were confirmed by dose-volume histograms, tumor control probabilities (comparable for the original, static and gated measurements; reduced with a factor 2 for the in-motion-non-gated delivery), conformity index, and dose heterogeneity values (increased with a factor 3 to 6 when motion was induced; comparable values between the theoretical, static and gated situations). The normal tissue complication probability was affected to a lesser degree. The breathing synchronization technique introduced an increased treatment time by a factor 3 to 4. **Conclusion:** The use of measured fluence fields, delivered in non-gated and gated mode, in the TPS is an interesting QA-tool to assess the clinical impact of dose blurring, as well as the potential of breathing synchronization to resolve this issue. **Conflict of Interest:** Part of this work has been supported by BrainLAB AG

SU-FF-T-106

Assessing the Impact of Radiotherapy Dose Uncertainties On Tumour Control Probability: Application of Equivalent Stochastic Dose (ESD)

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Purpose: To demonstrate a method of TCP evaluation that intrinsically accounts for the dose uncertainties. **Method and Materials:** The dose uncertainty is taken into account through the concept of an equivalent stochastic dose (ESD) defined as the dose to a voxel that results in the mean expected survival fraction from a process randomly depositing a dose D. Applying ESD to a non-uniform dose distribution yields the concept of equivalent uniform stochastic dose (EUSD). TCP was calculated to include dose uncertainty and dose inhomogeneity as TCP(EUSD). We show that Webb-Nahum and Niemierko-Goitein TCP models both converge to TCP(EUSD) when dose uncertainty is taken into account. Voxel control probabilities (VCPs) were modeled for a single voxel irradiated with a uniform prescribed dose of 60 and 70 Gy at 2 Gy per fraction. Effect of the dose fractionation on TCP in the presence of the dose uncertainty was also investigated using our TCP(EUSD) model. *Tolerance uncertainty* on the dose resulting in *tolerance TCP loss* (assumed as 5%) was calculated for a range of radiobiological parameters. **Results:** TCP degradation due to the treatment dose uncertainty in the whole tumour, as well as in its fraction was evaluated and shown that degradation of the TCP was controlled by the voxels where the dose is not known exactly. It is shown that cell radiosensitivity, the α/β ratio and the cell density each influence the TCP degradation due to the dose uncertainty. For a modeled tumour (α=0.3, α/β=10, $N_{0=}10^8$) irradiated with 60 Gy, 10 % dose uncertainty reduced the TCP from 95% to 45%. **Conclusion:** Presented TCP(EUSD) model demonstrated capability to robustly evaluate the loss of TCP due to the dose uncertainties. It is shown that the *tolerance uncertainty* reduces with decreased number of fractions indicating that hypo-fractionated treatments may require more accurate dose delivery.

SU-FF-T-107

Assessment of Dental Amalgam Backscatter with a Beacon Transponder Embedded Mouthpiece for Real-Time Tracking During Head and Neck IMRT

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Purpose: A mouthpiece embedded with Beacon® transponders (Calypso Medical) for continuous localization and tracking during IMRT head and neck irradiation was evaluated for backscatter to the oral mucosa. Dental amalgam can generate excessive backscatter dose to the oral mucosa during treatment. Study objectives were to measure backscatter dose from amalgams, transponders and mouthpiece relative to the oral mucosa. **Method and Materials:** A dental phantom having 16 of 28 teeth containing amalgam, and a prototype acrylic mouthpiece embedded with 3 transponders (1mm depth) were fabricated. To simulate overlying oral mucosa, a 1.5cm bolus was placed over the dental phantom and mouthpiece for baseline measurements. A TN502RD MOSFET dosimeter and TLD chips (3x3x1mm) with a 6 MV photon beam 10x10 cm^2 field (Elekta Precise) with and without mouthpiece were used for measurements. Backscatter was measured with and without the mouthpiece at a source-to-detector distance of 100 cm in a single field. To assess dosimetric effects of amalgam in the presence of the mouthpiece, a parallel-opposed field beam setup was used. **Results:** Standard amalgam causes dose increases of 24-29% at the tissue interface; however, backscatter decreases rapidly to 7-8% at 0.8mm depth. MOSFET and TLD measurements show the mouthpiece reduced backscatter dose by 15% (at 0.4 mm) for single beam and 6-8% for parallel-opposed beams. The transponders (1.8mm x 8.5mm) in the mouthpiece do not generate measurable additional backscatter. **Conclusion:** A mouthpiece when used for continuous target localization and tracking, can effectively reduce backscatter dose caused by amalgams, potentially decreasing mucositis. Embedded transponders do not generate measurable backscatter dose. **Conflict of Interest:** Mate and Zeller have a financial interest in Calyspo Medical

SU-FF-T-108

Automatic Machine Commissioning for a Helical Tomotherapy Machine

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Purpose: Develop and validate a new automated procedure to fully commission a helical tomotherapy machine with minimal human intervention and in a very short period of time. Compare the results of a commissioning using data based on water tank measurements and not using water tank measurements. **Method and Materials:** The process was performed in 5 HiArt helical tomotherapy machines. All of the machines where set to match a gold standard machine base on PDD, field sizes, output and output factors, and leaf characteristics. In a first pass, measurements were performed using water phantom for all of the commissioning measurements. After that, the same machine was verified using a new procedure (twinning) to generate a new gold standard under different measurement conditions. To determine data analogous to PDD an aluminum step wedge was used. The step wedge was mounted on the couch and was automatically moved in and out of the beam (as many times as needed) to determine energy through attenuation measurements. In order to determine the profiles a 2D arm was mounted on the machine to determine profiles in air. Also output and output factors were determined under the same conditions twinning. After that all the machines were detuned from the gold standard and then were set back to the gold standard using the twinning procedure and verified with the water tank. **Results and Conclusions:** It was possible to match machines to a reference gold standard either using water tank measurements or the twinning process. The later was less error prone and was 7 times faster than using water tank. Also, can be implemented almost without human intervention.

SU-FF-T-109

Automation of Monte Carlo Simulations For A Proton Therapy System

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Purpose: To develop a code system to automate the processes associated with Monte Carlo simulations of a clinical proton therapy system. **Method**

and Materials: A software system was developed that accepts a clinical prescription (beam range, range modulation, and field size) and generates a complete Monte Carlo simulation input file that includes all major components in the M. D. Anderson passively scattered treatment head plus one of several user-selectable phantoms. The simulations are automatically submitted to a 130 dual-CPU cluster. Post processing scripts were also developed to analyze the simulation results and generate required configuration data for the Varian Eclipse treatment planning system. Quality assurance procedures, such as design inspection, unit test, incremental integration test, regression test, and integration test, were performed to ensure the code system produces correct results. The code system was written in mainly C language, with some shell scripts, and it runs on the LINUX operating system. **Results:** A code system has been developed to automatically generate MCNPX input files, run simulations and perform post-processing of simulation results for a proton therapy system. The code system has been used to simulate dose profiles and generate required data for commissioning the M. D. Anderson proton therapy system. Over one thousand dose profiles were generated for different beam configurations by the code system in two months. Example beam data will be presented. **Conclusion:** The automated Monte Carlo code system has proved to be a useful tool for simulations of clinical applications in proton therapy. It allows for rapid modeling of proton therapy systems and the results of this study suggest that data from Monte Carlo simulations will play an increasingly prominent role in proton therapy projects, i.e., pre-clinical design, commissioning studies and routine clinical tasks.

SU-FF-T-110

Benchmarking MCNP Low-Energy Bremsstrahlung Modeling for Electronic Brachytherapy Simulations

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Purpose: Electronic brachytherapy (eBx) sources have been used clinically for over a decade; however, dosimetric characterization methods using measurements or calculations are not well-established. Monte Carlo methods for simulating electron transport, and subsequently photon production, have not been benchmarked to the same degree as for photon-emitting HDR ^{192}Ir or LDR ^{125}I brachytherapy sources. **Materials & Methods:** Towards better understanding the capabilities of MCNP5 to simulate radiation transport for the Xoft Axxent eBx source, this study presents a comparison of calculated MCNP5 results obtained using coupled electron:photon transport with measured bremsstrahlung spectra from the literature. Given the electron energy and target material, MCNP5 bremsstrahlung modeling accounts for photon energy, angle, and probability based on the cross-sections and angular distributions from NIST (Seltzer and Berger, 1985). The Axxent eBx source currently operates at 50 kV with electrons bombarding a ~ 1 μm thick high/low Z target. Pertinent high/low Z comparisons for thin targets, defined as materials thin enough to produce negligible electron absorption in the target, were available from Motz and Placious (1958) using 50 kV on 5 nm Au and 63 nm Al, from Cosslett and Dyson (1957) using 10 kV on 25 nm Au, and from Doffin and Kuhlenkampff (1957) using 34 kV on 25 nm Al. **Results:** Comparisons of calculations and experimental data indicate that bremsstrahlung angular peak, relativistically shifted forward, agreed within a few degrees with measurements in the literature. However, the overall simulated distribution exhibited angularly invariant regions in the forward direction, attributed to MCNP low-energy physics simplifications of the NIST dataset. Given that the brachytherapy target is ~ 50 times thicker, with resultant smearing of the energy/angular distributions, the practical impact of this effect is under investigation, and complementary EGSnrc simulations are in progress. **Conflict of Interest:** This research was sponsored in part by Xoft, Inc.

SU-FF-T-111

Bladder Dose Distribution in Cylindrical Brachytherapy Treatment

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Objective: This work compares the characteristics of dose volume histogram (DVH) and dose surface area histogram (DSH) analysis of contoured bladder volumes in HDR vaginal cylinder brachytherapy.

Method and Materials: CT scans were obtained on 20 patients with gynecological cancer who received in total 74 fractions of high dose rate brachytherapy treatment to the vaginal cuff, with the vaginal cylinder in situ. As part of an IRB approved study, the patients' bladder filling status was intentionally different for each fraction. The bladder was manually contoured for each treatment fraction including any fluid filling the bladder. The 3D bladder structure was reconstructed and its surface was extracted and represented with a triangular mesh. The dwell locations of the HDR source were identified for each fraction. Dose to each point on bladder was calculated according to the treatment plans. **Results:** The mean and standard deviation of volume (154.4 ±153.9 in cc) and the surface area (184.4 ± 91.8 in cm^2) of the bladder varied with filling status. The bladder filling has caused more variation in DSH than in DVH in the high dose region. The average dose for the most irradiated volume D2cc was 70%±18% of the prescribed dose. The average surface area receiving D2cc was 11.6 ± 2.0 in cm^2, or 7.5 ±3.1% of the total surface area compared to 2.4±1.8 % of the bladder volume. DSH is a smooth function with larger variation than DVH for doses over 70% of prescription. **Conclusion:** The nature of the bladder suggests that the surface area is a more realistic way of describing bladder. While both DVH and DSH may quantify the high dose region, surface area is more sensitive. As such DSH may offer a better correlation to clinical outcome.

SU-FF-T-112

Boost Within a Boost in Permanent Seed Implants: Dosimetric and Clinical Impact

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Purpose: Study the dosimetric and clinical impact on the target volume, boost volume (BV) and urethra of performing boosts in seed implants.
Method and Materials: 35 localized prostate cancer patients with detailed biopsy results were treated with permanent seed implants Personalized plans in which BV corresponding to regions of positive biopsy were generated intra-operatively based on a simulated annealing inverse planning algorithm. A second plan was generated for each patient without the BV. The dose objectives are 144 Gy to the prostate with a 3-4 mm margin, 2/3 (1/3) of the prostate covered by 150% (200%) of the prescription dose (PD), urethra V150 less than 10% and D5 should below 220 Gy. Finally, 100% of BV should receive 150% PD (or 216 Gy). **Results:** Comparing plans without and with BV show no significant change in the number of seeds, needles, prostate V100 and V200 ($p>0.37$). Prostate V150 and D90 show significant differences increasing from 65% to 70% and from 187 Gy to 191 Gy. By forcing the coverage of the BV, the 150% isodose lines (which extend outside the prostate) shift inside of the prostate. This small increase in prostate V150 leads to significant increases of the BV V150 from 79% (lowest 42%) to 94% (lowest 86%). BV do not translate to higher urethra doses (V150 and D5). BV are relatively small compared to the prostate V150 volumes (average ratio of 18%). Thus multiple seed reconfigurations inside the prostate are achievable to cover BV.**Conclusion:** Specific areas within the prostate can be boost to receive 150% of the PD with no impact on the urethra. Large volumes of these dose levels are inherent to the procedure. The plans lead essentially to a rearrangement of the seed positions. Potential radiobiological advantages could be obtained at no cost (procedure or time).

SU-FF-T-113

BrachyDose: A New Fast Monte Carlo Code for Brachytherapy Calculations

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Purpose: To develop a fast Monte Carlo code based on EGSnrc for accurate dose calculation around brachytherapy sources. **Method and Materials:** Sources and phantom geometries are modeled by using the Multi-geometry technique which allows various predefined geometry elements (eg, sources, applicators, catheters) a phantom geometry. Sources such as an HDR Ir-192 source and LDR I-125 or Pd-103 seed sources were modeled. One or more sources from a database can be duplicated many times and placed in arbitrary locations. Besides the above sources,

BrachyDose can calculate dose around a miniature x-ray-tube source since it is based on EGSnrc. It also can use CT data in the phantom geometry. Variance reduction techniques are applied to speed up computation time. Dose is calculated by scoring the collision kerma using a tracklength estimator. There is an option to reuse every photon which escapes from a seed as if it came from every seed in the implant with same direction relative to the seed itself. **Results:** The speed of the BrachyDose calculation is specified by the time required to attain an average of 2\% statistics in the central region of an implant of 125 seeds spaced at 5 mm separation in a 1000 cm^3 cubic phantom. The time required scales roughly as the inverse of the volume of the voxels. On an 2.4 MHz CPU, the computation time is 510 s for 1 mm voxels. The DVHs for 1 mm voxels are significantly different from those in 2 mm voxels. Changing phantom material from water to prostate tissue causes the dose to vary by +/-5% vs dose to water, depending on distance from the seeds. **Conclusions:** The Monte Carlo code developed is fast enough for routine clinical applications. Calculated dose values include inter-seed effects and other effects from tissue inhomogeneities.

SU-FF-T-114

Breath Coaching with Visual Feedback for End-Expiratory Gated Radiotherapy

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Purpose: To determine if breath coaching to maintain a consistent breathing amplitude at expiration is feasible in a clinical setting. **Method and Materials:** This technique consists of two phases of observation and active breathing to restrict the end-expiratory phase so as to never exceed the lower limit of the gate. The first phase consists of 2 minutes of observation followed by 3 minutes of active breathing using visual feedback, while the second phase consists of 2 minutes of observation followed by 8 minutes of active breathing again using visual feedback. The purpose of the 2-minute observation periods is to set the end-expiratory gate at a comfortable level for the patient. Following the first phase the patient assesses whether the lower limit of the gate is appropriate and if it can be maintained in a reproducible manner for an extended period without exhaling below the gate. We have studied ten healthy volunteers of varying ages. The RPM system (Varian) was used to monitor the respiratory cycles of the volunteers. The volunteers self-monitored their respiration via goggles that were turned on following each 2-minute observation period. **Results:** The visual feedback was the key factor to reproducibly maintain the end-expiratory gate. We were able to determine that all subjects were successful in sustaining their breathing pattern such that they did not exceed the lower limit of the gate and they were all able to do so comfortably. Only one volunteer would have needed to have the gate shifted upwards for actual treatment delivery. Only one volunteer would have needed to have the gate shifted upwards for actual treatment delivery. **Conclusion:** Breath coaching to maintain a consistent expiratory amplitude is feasible. It should not place a heavy burden on the patient during respiratory-gated radiotherapy.

SU-FF-T-115

Breathing Phase Information Extraction Method From Non-Gated CT

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Purpose: To evaluate feasibility and clinical usefulness of a new breathing phase extraction method from regular non-gated CT scans in order to minimize the uncertainty of the dose calculations due to the external and internal motion artifact, also known as breathing "ripple" effect. **Method and Materials:** Non-gated CT is acquired as usual for 3-D patient geometry reconstruction in 3-D conformal and IMRT treatment planning. A sub-set of CT slices is then selected based on the timing correlation of the visible "ripple" effect and a new 3D image is made with interpolation. The image extracted with the new method is similar to the images acquired with 4-D CT. At least two breathing phases can be reliably reconstructed: inhale and exhale. Gated 4-D CT is also acquired at the same time at four gated phases. Comparison is then made for center of mass coordinates, tumor volume and displacement between extracted and acquired breathing phased images. **Results:** CT scans from 7 radiosurgery lung and kidney patients were used in this study. The average differences for location and displacement did not exceed 2 mm in Left to Right and Anterior to Posterior directions. Superior-Inferior difference was up to 4 mm. Volume difference larger for the small tumors and went down when the tumor volume increased. Average volume difference was 9% with standard deviation of 14% for lung tumors with volume less than 10 cubic centimeters, and less than 8% and standard deviation of 6% for larger tumors. **Conclusion:** The breathing phase extraction method produced results comparable to the gated CT acquisition. While it may not be precise enough for the radiosurgery treatments, it is a good tool for planning fractionated treatments aiding in tumor delineation, defining PTV and assessing dose corrections due to tumor motion.

Conflict of Interest:

SU-FF-T-116

Calibration of the Perkin Elmer AG9 Flat Panel Portal Imager for Exit Dosimetry

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Purpose: The new and highly sensitive amorphous-silicon AG9 flat panel portal imager by Perkin Elmer allows imaging with extremely low doses. The purpose of this work is to establish the dosimetric response of the panel. Dosimetric calibration of the detector is also a necessary step for a dose reconstruction program under investigation. Methods and Materials: A convolution model was developed to map the flat panel images to equivalent dose in water at a depth of 1.5cm. The three model parameters are the flat-panel and water energy-deposition kernels, the flat-panel-to-water-dose conversion function, and the pixel sensitivity matrix. They account for differing flat-panel and water energy responses, field size effects, and the panel's pixel nonuniformity. To determine these parameters, identical setups with the flat panel and with a water phantom were used to carry out numerous measurements. To validate the model, 10cm and 5cm square fields were delivered through 16cm of solid-water slabs and a cylindrical solid-water QA phantom. The flat-panel converted dose profiles were compared with that measured in the Wellhofer water tank. **Results:** Both the flat-panel and water kernels decrease sharply with distance. The magnitude of the flat-panel kernel was greater, possibly due to the additional scatter in the high-density panel material. The conversion function varies with the off-axis distance and is nearly linear as the attenuation thickness varies. The sensitivity matrix values were approximately within 1% of unity, demonstrating good pixel uniformity of the panel. Validation tests showed that the model-extracted dose agrees with measurements to within 1%. **Conclusion:** A good understanding of the dosimetric response of the AG9 flat panel was achieved. The developed convolution model was shown to be accurate and suitable for generating energy-fluence maps for 3D dose reconstruction. **Conflict of Interest:** Research supported by Siemens.

SU-FF-T-117

Can Current Prostate IMRT Be Further Improved with Immersive Virtual Reality Simulation?

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Purpose: To further optimize beam orientations for axial 7-field prostate IMRT plans with enhanced geometric volume analysis utilizing an immersive virtual reality simulation, a software which enhances the visualization of simulation using 3D stereo-scopic data projection. **Materials and Method**: Eight prostate IMRT cases were selected, in which 7 beams were equi-spaced in the axial plane, for a supine patient. D_{95} of PTV was normalized to 45.0Gy, the dose used for the initial treatment course. Beam geometry was then further optimized using an immersive virtual reality simulation tool – RTStar (provided by the U. Hull, UK). Consequently, with the exception of the AP field, all beam projections were rotated more anteriorly. Viewing through the most posterior beams, only 50% of overlap between PTV and the rectum was observed. In addition, two anterior oblique beams were tilted off the axial plane, 20º inferiorly, to clear the bladder. Use of the 3D stereo-scopic viewing eliminated risk of collision with the patient. Comparable IMRT plans were then calculated with similar modulation intensity level and number of MLC segments. **Results:** A better dose homogeneity of PTV was indicated by 1.9% reduction in global maximal dose ($p<0.01$), and 1.3% reduction of dose value in 5% high dose region of PTV ($p=0.02$).

Some rectal dose improvement was suggested with a 2.3% lowered hot spot with 10cc rectum enclosure (p=0.04). The bladder mean dose and the high dose value involving in 30cc bladder were reduced by 12.9% (p<0.01) and 3.9% (p=0.02) respectively. **Conclusions**: Immersive virtual reality simulation benefited the process in optimizing the beams used in this study. A deliverable, non-coplanar beam arrangement improved dose homogeneity of PTV, dose sparing to the bladder and reduced high rectal dose in prostate IMRT. Research sponsored by Boca Raton community hospital corporation

SU-FF-T-118

Can the Use of Respiratory Gating Reduce Radiation Dose to Heart in Whole Left Breast Irradiation Treatment? – A Preliminary Study

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Purpose: To investigate the potential benefit of using respiratory gating technique to reduce radiation doses to patient's heart in whole left breast irradiation treatment**. Method and Materials:** Conventional helical CT scan and retrospective 4D CT scans were acquired for 5 left sided breast patients**.** The 4DCT scans were sorted into 10 phases per respiratory cycle**.** Treatment plans, which consisted of two wedged tangential fields, were designed based on the helical CT scan**.** The PTV coverage, heart and lung doses in this plan were used as references for comparison**.** 10 separate optimal plans were generated from the 10 different phases obtained from the 4DCT images**.** All beam parameters, except for beam energy and wedges, were adjusted so that the PTV coverage in these plans was similar to or better than that in the corresponding reference plan**.** The heart and lung doses were then computed from these plans and compared to the corresponding doses in the reference plan**. Results:** The present results show that one patient would benefit from gated treatment at any given phase in terms of heart dose reduction**.** For four other patients respiratory gating would reduce dose to the heart**.** Gating at a given phase would reduce mean dose to the heart by 24%, 17%, 8% for 3 patients; for another patient a 17% reduction in maximum dose to the heart was found while the impact to the mean dose was insignificant**. Conclusion:** The use of respiratory gating in the irradiation of whole left breast treatment has the potential to reduce dose to the heart**.**

SU-FF-T-119

Cardiac Dose Heterogeneity and Relationship to Tumor Location in Patients Receiving Radiation for Lung Cancer

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Purpose: To assess dose heterogeneity to subregions of the heart (e.g**.** four chambers), and its relationship to tumor location in patients irradiated for lung cancer**.** Methods and Materials**:** 236 patients receiving 3D-planned radiotherapy for lung cancer from 1991-2005 were retrospectively analyzed**.** Pre-treatment CT planning images were segmented to define the whole heart, four cardiac chambers, and aortic root**.** For each patient, the mean dose to the heart and each cardiac subregion was calculated, reflecting tissue density inhomogeneities**.** Population average of those doses, their differences, and 95% confidence intervals were computed**.** Patients were divided into subgroups based on tumor location (left vs right, superior vs inferior, and central vs peripheral)**.** Differences between subgroups were assessed using Student t-tests**. Results:** Mean doses to the whole heart and each subregion are shown in Figure 1**.** Compared to the mean heart dose (the parameter typically considered in treatment planning), atrial doses are higher (11Gy for left and 3Gy for right), ventricular doses are lower (9Gy for left and 5Gy for right), and aortic root dose is 23Gy higher**.** Table 1 shows the impact of tumor location on cardiac subregional dose heterogeneity**.** Dividing patients into superior versus inferior lung tumors changes the dose to most subregions**.** Similarly, dividing patients into central versus peripheral tumors leads to dose changes in several subregions, but only for peripheral tumors**.** Dividing patients into left versus right lung tumors only changes the dose to one subregion**. Conclusions:** Doses to cardiac subregions are significantly different than mean dose to the whole heart**.** Treatment planning using DVH of whole heart does not adequately portray doses to cardiac subregions, which have distinct functions in cardiac physiology**.** DVHs inherently discard all spatial information and may be suboptimal to describe exposures to heterogeneous organs such as the heart.

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SU-FF-T-120

Characterisation of Dose in SBRT Lung Via Monte Carlo

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Purpose: To accurately characterize the doses received by static lung lesions, as well as doses to the critical structures for the serial tomotherapeutic IMRT delivery method used for SBRT in our clinic. **Method**: 77 SBRT lung patients previously treated with doses calculated using the effective path length/Finite size pencil beam (EPL/ FSPB were retrieved. The critical structures (ipsi-lateral lung, contra-lateral lung, major airways, spinal cord and esophagus) were redelineated in order to standardize the contouring. All plans were run with Monte Carlo (MC), EPL/FSPB and No inhomogeneity correction (NI/FSPB). The intensity maps and MUs were the same for all three plans. The minimum, maximum and mean target doses were compared with MC calculation used as the benchmark. The normalized total dose, NTD; minimum, mean and maximum doses for critical structures were also compared. **Results**: The mean CTV volume of the 90 lesions presented here is 35.6 cm^3 (range: 0.3-370.2 cm^3). The minimum dose to both CTV and PTV were overestimated by the EPL/FSPB algorithm by an average of 17.3 ± 7.8% and 20.6 ± 10.8% of prescribed dose respectively. The absolute mean deviation in the minimum CTV and PTV doses were 5.7% (0.2-20.1) and 10.6% (0.03-27.3) respectively with NI. The magnitude of deviation depends on target location (embedded dense soft tissue, surrounded by lung and its proximity to a more dense interface) and dimensions. The minimum dose, mean dose and NTD for the lungs were in good agreement with MC. Larger, localized discrepancies exist for maximum dose. Doses to the other critical structures were generally in good agreement with those predicted by MC. **Conclusion**: MC dose calculation may prove valuable in accurately assessing the delivered dose in SBRT and may, thus, contribute to a more informed decision on the optimal dose and fractionation scheme.

SU-FF-T-121

Characterization and Real-Time Measurements of Optical Density with GafChromic EBT Film

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Purpose: Over the last few decades, various groups have investigated optical fiber-based dosimeters for *in vivo* measurements**.** Recently, two radiochromic films have also been considered for real-time *in vivo* point-based optical dosimetry, and both GafChromic MD-55 and GafChromic EBT films faired well in several criteria**.** However, GafChromic MD-55 was shown to have the change in optical density depend both on dose rate and on temperature, as measured immediately at the end of a given exposure**.** To continue with the search for a suitable medium for real-time fiber-based *in vivo* dosimetry, GafChromic EBT film is also being investigated for dose rate and temperature effects**. Method and Materials:** 1 cm × 1cm pieces of film were irradiated with a 6 MV beam within a 30 cm × 30 cm × 10 cm Solid Water phantom fitted with optical fibers for real-time measurements, using a 10 cm × 10 cm field at SAD, 100 cm SAD, and 1.5 cm depth**.** Each exposure delivered a dose in 5 to 1000 cGy range at a dose rate in 14 to 520 cGy/min range**.** Changes in OD obtained immediately at the end of each exposure were compared**.** The percent uncertainty in ΔOD for a given dose was calculated by using all the values obtained, regardless of the dose-rate used. **Results:** The percent uncertainty ranged between 1.8% and 3.6%, with an average of 2.8%**.** The expected variation in ΔOD within a single sheet of GafChromic EBT film for a given dose is 1.5% (two standard deviations)**.** The average increase in uncertainty is 4%.**Conclusion:** An increase in uncertainty of real-time ΔOD measurements is observed when variations in dose-rate are introduced for the doses in 5 to 1000 cGy range, and dose-rates between 14 and 520 cGy/min.

SU-FF-T-122

Characterization and Use of EBT Radiochromic Film for IMRT Dose Verification

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Purpose: To quantify and evaluate the use of the new EBT GafChromic film for its implementation in routine IMRT QA. **Method and Materials:** The new film was examined using a characterized flat-bed scanner for several properties including polarization effects with scan angle and delivered dose, dose sensitivity, dose uniformity, OD time evolution post exposure, and dose response in comparison to water. The film high elasticity and relative insensitivity to water immersion allowed for its non conventional use in verifying dose distributions on curved surfaces. The film was wrapped into a cylindrical geometry inside an in-house built cylindrical phantom and then immersed in water. Calculated dose distributions from the TomoTherapy treatment planning system (TPS) were then compared to the film's measured IMRT deliveries for 10 IMRT cases (5 Head and Neck, 5 prostate). **Results:** The film's intrinsic polarization was shown to be a function of delivered dose and could significantly affect the scanner's OD output readout. Film uniformity was shown to improve with delivered dose from ±5% for 50 cGy to nearly ±1.5% at 200 cGy. In addition, the film's OD was shown to saturate within 2 hours post exposure to a 2Gy dose, making it the fastest and least noisy RCF film so far. An excellent agreement was found between scanned water and film PDDs indicating the EBT energy response with depth is similar to water. Excellent agreement between predicted and measured isodose distributions and dose profiles were seen using the EBT film based on 10 IMRT deliveries. **Conclusions:** This work indicates that this new RCF film possesses unique and improved characteristics which allows for its use in routine patient-specific IMRT QA. These encouraging results have motivated us to design an in-house cylindrical phantom to verify dose beyond 2D planar surfaces and in water phantoms.

SU-FF-T-123

Characterization of MOSFET Response to the Xoft X-Ray Brachytherapy Source

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Purpose: To study the response characteristics of MOSFET dosimeters in the energy range of the Xoft Axxent Electronic Brachytherapy system. These devices can be used to measure skin dose in breast HDR treatments. While MOSFETs have flat energy response at energies above 1 MeV, at the lower energies relevant to this device spectral dependence is anticipated. Therefore it is important to characterize the response for the source both bare and filtered by varying amounts of absorber to simulate different source-to-skin distances. **Method and Materials:** The Thomson-Nielsen MobileMOSFET dosimetry system was characterized with respect to a calibrated air ionization chamber for a Xoft Axxent x-ray source operating at 50 kVp. A sequence of aluminum absorbers were introduced to study how changes in the spectrum due to filtering affect the cross calibration of the MOSFETs. The Thomson-Nielsen system supports continuous readout at 10 second intervals while under irradiation, allowing detailed comparison of the time series of dose readings, and an evaluation of the real-time capabilities of the system. Results: Thomson-Nielsen MOSFETs had excellent linearity, with deviations throughout irradiation up to 14 Gy on the order of 3% or less. Changes in calibration as a function of absorber thickness were observed, and can be characterized by degree of change per fraction of attenuation. Conclusion: Thomson-Nielsen MOSFET dosimeters provide skin dose measurement capability with an accuracy on the order of 3%, providing corrections are applied to account for the distance from source to skin. Without these corrections the errors will be as much as 60% compared to an unfiltered source, but in practical use, where significant filtering will always be present, uncorrected errors are likely to be no more than 10%. Conflict of Interest: Xoft Inc. is currently in educational and commercialization discussions with several MOSFET system suppliers.

SU-FF-T-124

Clinical Evaluation of the Performance of a Fuzzy Logic Guided Parameter Optimization for Inverse Treatment Planning

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Purpose: To evaluate the effectiveness of a Fuzzy Logic guided parameter optimization method for inverse treatment planning, in comparison with the results achieved by routine trial-and-error method. **Method and Materials:** The optimization algorithm was developed and integrated into a commercial planning system (Varian Eclipse). 10 prostate IMRT cases previously planned and approved by experienced planners were re-optimized using this automated method with the same beam geometry. The original dose-volume histogram (DVH) constraints were used as the initial parameter setup of the automated method. For each organ, the output dose was evaluated based on the percentage of dose received by a specific percentage of volume. The average dose difference between the automated and manual plans was calculated over a set of specified percentage volumes (99%, 80%, 60%, 40%, 20%, 10%, 5%, 1%). In addition, an experienced clinical physicist evaluated the acceptability of the plans generated by the automated method in terms of isodose distributions and DVHs. **Results:** Adoption of the automated method achieved both a comparable coverage of the planning target volume (PTV) and a substantial dose sparing of organs at risk (OARs). The mean dose was reduced by 30% for bladder, and 25% for rectum. There were few hot spots observed on OARs due to the over-emphasis of PTV dose coverage. **Conclusion:** Preliminary results show that the automated parameter optimization method results in a significant dose reduction of OARs while maintaining a comparable PTV dose coverage. The automated method is able to relieve the burden of routine trial-and-error procedures done by planners, and has the potential to improve the resulting plan. However, minor manual intervention is still necessary to incorporate certain case-specific information, which is beyond the capability of the automated method. This study is partially supported by a research grant from Varian Medical Systems.

SU-FF-T-125

Clinical Evaluations of a Gantry-Mounted Laser Digital Source Skin Distance (SSD) System

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Purpose: To evaluate accuracy and reproducibility of an experimental device recently installed in our department to measure the SSD based on laser reflection. **Method and Materials:** The PICTOR DDI System includes a sensor that determines the SSD. The digital value is recorded on the daily electronic portal imaging (EPI). We evaluated this system for over 4 months including weekly phantom measurement and comparison with ODI measurement. An alignment phantom was constructed to verify measurement values and to check the linearity of the software. The phantom incorporates a leveling plate and a 4 steps phantom. The leveling plate was set to the ODI's 100 SSD and then the phantom was moved so to measure the SSD to the 4 steps. SSD data from 53 patients were recorded to EPI system and compared with manual measurements. Different fields for prostate cancer were combined. For breast IMRT only medial beam was measured. The system was calibrated only once after the installation. **Results:** The stability of the system obtained by the weekly checking is 1.3 ± 0.5 mm. Mean and Standard Deviation (SD) at the leveling plate and at the 4 phantom's steps were 0.9 ± 0.2, 1.2 ± 0.4, 1.7 ± 0.5, 1.1 ± 0.5 and 1.4 ± 0.5 mm, respectively. Analyzing the patient's SSD, the average difference between manual and laser measurement was 1.9 ± 3.1 mm, -1.0 ± 7.8 mm and 1.5 ± 2.8 in prostate, breast and other cancers, respectively. **Conclusion:** The device appears accurate within 2 mm in 95% confidence level. The use of this device reduces manual measurement time. Recording SSD data directly into the EPI allows more frequent measurements. It can potentially be integrated into the Linac as a replacement for ODI. **Conflict of Interest:** The system was provided by LAP of America.

SU-FF-T-126

Clinical Experience Using Dynalog Files for Verification of IMRT Delivery

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Purpose: Validation of IMRT field delivery and the dynamic leaf movement during treatment is an important part of the IMRT QA procedure. In the past this was done using film during treatment. In this presentation, we summarize our experience using the dynalog files to validate the delivered fluence pattern of individual IMRT fields for each patient. **Method and Materials:** The DynaLog files were generated during IMRT delivery on Varian Trilogy and 21EX linear accelerators. They represent the actual leaf movement, as MLC leaf positions were recorded, during delivery, every 50 ms. Argus IMRT QA software was used to interrogate the dynalog files after delivery for evaluation. The delivered and planned fluence pattern can be displayed for comparison as well as fluence difference and Gamma function values. Maximum and average fluence difference and Gamma function values can be employed for quantitative analysis, as well as actual versus planned leaf positions and speeds. The pass/fail status of each IMRT field can be set based on pre-determined parameters. **Results:** We have employed the Argus IMRT QA software in analyzing the fluence patterns and leaf motions for all IMRT fields used for patient treatment. Several hundred fluence patterns were analyzed on 100 patients treated so far. The average and maximum gamma function value of each field was analyzed to determine appropriate limits for the pass/fail criteria in accordance with our clinical data. **Conclusion:** Verification of delivered fluence patterns is an important part of the IMRT QA process. It assures the accuracy of IMRT delivery on a daily basis. With the aid of Argus IMRT QA software, validation of all the fields used for IMRT treatment can be performed within minutes for qualitative and quantitative analysis. With the proper choice of limits for test parameters, this approach further ensures the quality of IMRT delivery.

SU-FF-T-127

Clinical Feasibility of Jaw-Only IMRT Plan for Prostate Cancer

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Purpose: To investigate the feasibility of inverse IMRT plans generated with jaw only, compared to IMRT plans with multi-leaf collimator (MLC) for patients with the prostate cancer. **Method and Materials:** For five patients, two different planning techniques were used to generate inverse IMRT plans. One was the aperture-based IMRT planning using MLC (MLC plans) and the other used jaw only (JO plans), available in a commercial planning system. The conventional 7 beams were employed. The planning goal was to deliver 72 Gy to > 95% of the PTV while keeping 10% of the rectum and 15% of the bladder receiving < 60 Gy and mean dose of the bulb < 30 Gy. For the JO plans, four different numbers of apertures/beam (3, 4, 5, and 6) were tested, compared to the MLC plans set to 3 apertures/beam. All plans (one MLC and four JO plans) for each patient were analyzed using conformal index (COIN), defined endpoint doses to the sensitive structures, total number of segments, and total delivered monitor unit. For each patient, planning dose constraints were kept the same for MLC and JO plans. **Results:** The COIN values for JO plans were generally increased as the number of apertures/beam increased, up to the same value as the MLC plans. The number of total segments for the JO plans was gradually increased (21, 27, 34, 40) as the number of apertures/beam increased (3, 4, 5, 6), compared to 21 segments for the MLC plans. However, the delivered MU values and doses to sensitive structures were patient-specific and independent of the number of apertures/beam in JO plans. **Conclusion:** For centers without MLC collimator, it is possible to deliver inverse planned IMRT plans using jaws only for patients with prostate cancer. **Conflict of Interest:** Research sponsored by Prowess Inc.

SU-FF-T-128

Clinical Implementation of a New Elekta Dedicated-Stereotactic Linac Into Radionics Treatment Planning System

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Introduction: A new Elekta "Synergy S" dedicated stereotactic machine has been commissioned and clinically implemented. This linac has special features, including a kV cone beam CT (CBCT) and a multileaf collimator (MLC) system, termed as "Beam Modulator" (BM), with no back up jaws. Dosimetric parameters of the BM are compared with those of Radionics mini multileaf collimator (MMLC). The two MLC systems have different dosimetric parameters, chiefly due to different shapes, field sizes and isocentric distances. The effects of these differences on tumour dose coverage and sparing organs at risk (OAR) are evaluated. **Methods and Materials:** The leaf thickness and maximum field size at the isocentre are 4mm and 16x21cm for the BM and 3.75mm and 10x12cm for MMLC. The leaf-bottom isocentric distances of the two systems are 45.2cm and 33cm, respectively. Radionics treatments planning (XKnife RT3.01) is used for planning comparison. Dose penumbras and percentage depth doses were measured using diode detector and XV2 films for different field sizes. CBCT doses were measured using an ion-chamber and MOSFET. Two different clinical cases were chosen for the treatment planning comparison. **RESULTS:** MMLC dose penumbras (80-20%) at dmax for a 9.6x10.4cm field were 5.4mm and 5.6mm for the leaf sides and leaf ends, respectively and 5.8mm and 6.5mm for BM. As a result, Radionics MMLC has the advantage of better sparing of OARs. Also, Radionics MMLC delivered the prescribed doses using fewer segments and less number of monitor units by up to 20%. The CBCT dose to head phantom was in the range of 1.5 to 3.0 cGy per scan.**Conclusion:** In this work it is shown that the above MLC systems are overall clinically comparable, with Radionics MMLC marginally better sparing normal tissues. The Elekta BM however has the advantage of larger field size and better isocentric clearance.

SU-FF-T-129

Clinical Implications of .decimal Solid IMRT with Pinnacle Treatment Planning System

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Purpose: Recently, the .decimal Solid IMRT solution has become available to Pinnacle users. We explored the implications of this solution and the appropriateness of its use in the clinic. **Method and Materials:** Using a Varian 2300EX with 120-leaf MLC, two Siemens Machines with and without 80-leaf MLCs, a variety of sites were explored and optimized plans determined for conventional MLC delivery and compared to the .decimal Solid IMRT solution where the ideal Open Density Matrices (ODM) from Pinnacle[3] is converted into an array of solid modulator thicknesses using the .decimal p.d software and re-importing them back into Pinnacle[3] for final dose calculation. We investigated the following key practical considerations: (1) What treatment machines would most benefit? (2) How does it impact the overall quality and efficiency in planning? (3) What are the cost benefits or revenue implications? (4) What safety precautions are necessary, i.e. with regard to R&V, Film or Ion Chamber QA? (5) How do treatment times and number of MUs compare to MLC based treatments? (6) How long does it take to implement the solution? (7) What treatment sites most benefit? **Results:** For the Siemens machines, we found reduction in the planning time, better quality plan and more efficient delivery, with less MUs, faster delivery times and improved agreement in film QA and IC measurements. For the Varian 2300EX with 120-leaf MLC, the need for solid IMRT was not significant but can prove useful when treating large sites, negating the need for splitting the fields. **Conclusion:** We the found that solid IMRT solution to be valuable asset to our clinic, allowing our clinic to increase the number of IMRT treatments and treatment sites, extend the life and usefulness of older non-MLC linear accelerators, provide better quality plans and reduced planning time.

SU-FF-T-130

Clinical Significance Based IMRT QA Approach

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Purpose: Patient-specific IMRT treatment quality assurance procedure often consists of the measurement of 2-dimensional intensity map and absolute dose. The data is compared with the computed results from TPS using a standard pass-or-fail criterion. However, the same dose discrepancy may not have the same clinical significance depending on its location. For instance, the consequence of a hot-spot in PTV is different than in spinal cord. In this project, we intend to develop a method that considers the locations of the dose discrepancy into the IMRT QA pass-or-

fail decision-making. **Method and Materials:** Compensator-based IMRT treatments and PLUNC were used in this study. The 2-dimensional dose distribution was acquired with the EDR2 film and Mapcheck. The measured point dose was back-projected to compute the derived intensity map of the IMRT field. Using the measurement-derived maps the patient dose is recomputed on the planning CT image. The dose discrepancy points between the original and measured plan were visualized by subtracting two dose grids. The QA test was performed in the 3-dimentional space with the exclusion of 5% hot-spots in PTV and cold-spots in the critical structure. **Results:** The method was applied on two simulated clinical cases:(1) a 5-field H&N IMRT with one defective compensator;(2) a 5-field prostate IMRT plan with intentionally modified QA maps of three fields. In each case, the dose discrepancy points were computed and displayed in the patient CT. The QA passing rate is computed using both conventional 2D and revised 3D method. **Conclusions:** We reconstruct the 3D dose distribution in patient planning CT from the intensity maps obtained from the 2D IMRT QA measurement. A QA statistics method is proposed to include the location of dose discrepancy points. This approach promises a new IMRT QA pass-or-fail standard that considers the clinical significance of dose discrepancy measured in IMRT QA.

SU-FF-T-131

Clinical Use of Linear Array MOSFET for Urethral Dose Verification in Prostate High Dose Rate Brachytherapy

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Purpose: To investigate the use of linear array MOSFET as in *vivo* dosimetry detector to determine the urethral dose for a single and multiple fraction during the prostate HDR treatment. **Method and Materials:** Commercially available Linear Array MOSFETs with 5 individual MOSFET was inserted into the 18 gage Foley catheter right after the HDR prostate implant. Measurements were performed in 25 patients receiving total of 2400cGy HDR boost in 4 fractions with 600cGy per fraction. The urethra dose was measured right after first fraction for all the patients and also subsequent fraction in 5 patients in terms of reproducibility of urethra dose. The exact location of the MOSFET was determined using radio-opaque marker and the point dose for each MOSFET was determined using CT-base treatment planning. **Results**: A Linear Array MOSFETs was placed in such a way that the first MOSFET being slightly above the bladder neck with the average reading of 75%±18% of the prescribed dose since it is beyond the base of the prostate. The dose was increased to maximum of 128% of the total dose within the prostate gland and decreased to 40% or less of the total dose beyond the apex of the gland. There was an excellent correlation of 2.8% between the MOSFET reading and treatment planning dose calculations. The MOSFET reading comparison between first and second fraction also correlated within 2.3%. **Conclusion**: MOSFETs are suitable for *in vivo* dosimetry during prostate high dose rate brachyhterpy not only to verify the dose across the urethra but also to verify that the needles are maintained in its exact same position as the first fraction. Any unexpected variation in urethra dose compared to initial treatment plan can be corrected in the subsequent fraction as a result of this dose verification procedure.

SU-FF-T-132

Clinical Validation of Solid IMRT with the Pinnacle3 Radiation Treatment Planning System

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In this work, we investigate a new “Solid IMRT” solution that works with the Pinnacle3 treatment planning system. The .decimal Solid IMRT solution involves exporting the ideal Open Density Matrices (ODM) from the Pinnacle[3] treatment planning system, optimizing the transformation of each ODM into an array of solid modulator thicknesses with a special software package, and importing these thicknesses and necessary supporting information to Pinnacle[3] for the final dose calculation. In order to validate the process and the accuracy of the IMRT dose delivery, three Solid IMRT plans (a prostate, a head and neck, and a breast) were created in Pinnacle[3]. The plans had the following number of beams/gantry angles: prostate plan, 5; head & neck plan, 7; and the breast plan, 2. Solid IMRT modulators were designed, built, and verified for individual beams. In order to conduct QA on the fabricated solid modulators, both film and diode array dose measurements were collected. The measured dose distributions were analyzed vs. calculated QA planar doses from the TPS. The process yielded high-quality dose distributions and excellent agreement between the calculated and measured dose values. This study presents a valuable solution that enables Pinnacle users to upgrade to Solid IMRT delivery. Research sponsored by .decimal, Inc. corporation

SU-FF-T-133

Commissioning Electron Beams with Monte Carlo Simulation Based On Large Field Measurements

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Purpose: To commission electron beams using measurements made with the jaws wide open (with no applicator) along with state-of-the-art Monte Carlo simulation. **Method and Materials:** Central axis depth dose curves and dose profiles of 6-21 MeV Primus electron beams were measured for the 40x40 cm field and a comprehensive set of field sizes for all square applicators. Monte Carlo treatment head and water phantom simulations were done with the EGSnrc system using the BEAM and MCRTP user codes, respectively. The measured data for the 40x40 cm field was used to estimate the source and geometry parameters used in the smaller-field simulations. Calculated output and dose distributions were compared to measurement. **Results:** Dose distributions calculated with this large-field commissioning approach generally compared to 2%/2 mm or better with diode measurement. Relative output factors compared to 2% for the largest field available for each applicator. Output with cut-outs, relative to the field with no cutout, also agreed within 2%. **Conclusion:** EGSnrc is sufficiently accurate for commissioning electron beams, given a good match to a few carefully done measurements for the 40x40 cm field with no applicator. This demonstrates the use of Monte Carlo simulation to commission electron beams, with only a few measurements. Measurements needed include the 40x40 cm central axis depth dose curve and cross-plane and in-plane profiles at d_{max}, and the ROF for the largest field of each applicator for all beam energies. Output and dose distributions for small and large fields for each applicator should be measured to verify the accuracy of the simulation.

SU-FF-T-134

Commissioning Enhanced Dynamic Wedges Utilizing Mapcheck Device and Comparing with Film and Ion Chamber Dosimetry

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Varian Enhanced Dynamic Wedge (EDW) is a wedge technique where no physical modifier is used to create a wedge dose profile. The wedge dose profile is created by sweeping one of the Y jaw from open to closed position while other Y jaw and the X jaws stand still throughout the treatment. Because of the collimator motion, different parts of the field are exposed to the primary beam for different lengths of time.The motion of the jaw is controlled by a computer and the dose vs. collimator relationship to be followed in treatment mode is contained in a dose vs. jaw position table called Segmented Treatment Table (STT). The EDW provides wedge angles of 10°, 15°, 20°, 25°, 30°, 45° and 60° for both symmetric and asymmetric field sizes. EDW does not cause beam hardening and extra scatter to patients as compared to physical wedges. We measured the Wedge profiles using mapcheck device which contains 445 diodes in 2D array at various depths such as Dmax, 5cm, 10cm and 20cm. Dose profiles were also measured using EDR2 film and RIT software and 0.125cc ionization chamber. Profiles were compared with TPS generated profiles. We found that profiles measured with Mapcheck device agrees well within 1-4% with film & ionchamber measurements and TPS calculations. Mapcheck device is a very useful and time saving tool for commissioning and QA of EDW wedges.

SU-FF-T-135

Commissioning of Multi-Leaf Collimator for Fast Neutron Therapy

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Purpose: To collect and analyze data required for modeling of d(48.5)+Be fast neutron beam and shaped by newly installed multi-leaf collimator (MLC) replacing previously used multi-rod collimator (MRC). **Method and Materials:** The MLC is of semi-focused design and consists of 60 leaf pairs operated under vision control. The leaf ends are straight, while the sides of the leaves are tapered to match the beam divergence and project 5 mm at isocenter plane. The leaf thickness is 300 mm of steel, and the MLC is the primary beam shaping device. The measurements along the central axis as well as lateral profiles were done in a water phantom. In the build-up region the central axis depth dose curves were combined with data obtained from the measurements using thin window extrapolation ionization chamber. The output factors were defined at 0.9 cm depth in phantom and in free air by means of small volume Tissue Equivalent (TE) ionization chamber and miniature pin diode. In addition TE/Mg(Ag) paired ionization chambers were used to separate the neutron and gamma components in phantom as well as in free air. **Results:** No significant variations of the central axis depth doses were observed compared to MRC. Penumbra measured between tapered leaf sides was smaller than penumbra measured between straight leaf ends. The differences were largest at shallow depths and for large field sizes: 7 mm for 25 × 25 cm^2 field decreasing to less than1 mm for fields smaller than 15 × 15 cm^2. Linear relationship between the actual leaf end position and field size was observed. The gamma component at 0.9 cm depth in phantom increased with the field size from 1.5% to 3% and from 0.4% to 0.74% in air. **Conclusion:** A set of beam data measured for neutron MLC was used in beam modeling.

SU-FF-T-136

Commissioning of the EYEPLAN V3.01 at LLUMC

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Purpose: To update the technology that has been utilized for designing proton dose distributions for the treatment of ocular melanoma at Loma Linda University Medical Center since 1990. **Method and Materials:** For the past decade the treatment planning system utilized for ocular melanomas at LLUMC has been a *Digital VAX 4* workstation. This workstation utilizes software that was developed at MGH specifically for the treatment of ocular melanomas. Although the system has proven useful in the treatment planning process, the technology is antiquated and can be improved by switching to a PC based platform. A new eye treatment planning system has been commissioned and implemented at LLUMC. The new system, EYEPLAN *3.01*, is PC based and was developed by *CCO, Radiotherapy Quality System* in Clatterbridge, England. Following treatment machine data entry into the new treatment planning system, the commissioning process consisted of the following: Confirmation of correct clip entry orientation, proton range and modulation values, lateral margins, and dose volume histograms. Several plans have been duplicated on both the old system and EYEPLAN for comparison. **Results:** Proximal and distal range comparisons are within 0.2mm. In the patient plan comparisons the same tumor range was generated to within 0.1mm. In addition the isodose distributions showed virtually no visible differences. The aperture cutouts generated by each of the programs were within 0.5mm.

Finally, EYEPLAN 3.01 has the capability of including an eyelid in the path of the beam. **Conclusions:** The state-of-the-art PC based treatment planning system, EYEPLAN, has been successfully commissioned for clinical use at Loma Linda University Medical Center. Comparisons made between the old planning system and EYEPLAN suggest that the design of proton dose distributions remain consistant.

SU-FF-T-137

Commissioning the Eclipse AAA Algorithm with Golden Beam Data

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Purpose: Evaluation of the accuracy of Eclipse AAA TPS when commissioned with Golden Beam or measured data. **Method and Materials:** Two cancer centers independently performed preliminary evaluation of the Analytical Anisotropic Algorithm (AAA) implemented in Eclipse TPS. The AAA photon algorithm was commissioned with vendor supplied "Golden Beam Data"(GBD). We measured central and off-axis profiles in several beam configurations including: open square, rectangular and asymmetric (half-blocked) beam; wedged square and half-blocked beam; square fields at three different source to surface distances; open and wedged beam at oblique incidence; beams shaped using cerrobend blocks and MLC. The measurements were performed on the Varian 2100 EX linear accelerators installed at the two institutions. After the initial tests, Eclipse was recommissioned with measured data from one of the machines. **Results:** The evaluation of the profiles was performed in the buildup, penumbra, inner and outer beam regions as per AAPM TG53. With the GBD the agreement of the measured and calculated profiles at the two institutions was very good in all regions except for the inner beam region on one machine. The tests that had a significant number of failures in the inner portion of the beam were mainly those cases where the TG53 tolerances are very tight. In these cases a significant number of points were just beyond the tolerance, and some of the off axis scans had 100% fail. On one particular test case where 16 profiles were measured for a particular geometry, 59% of points passed in the inner section with GBD, while 91% of points in that region passed once the beam was commissioned. **Conclusion:** When Eclipse is commissioned with GBD it was quite accurate, however, commissioning with measured data can improve the overall match. **Conflict of Interest:** Funding provided by Varian

SU-FF-T-138

Comparison of Change in Optical Density Between Three Radiochromic Films Due to 100 CGy Dose-To-Water Delivered by X-Rays in the 75 KVp to 18 MV Range

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Purpose: Over the last few decades, optical fiber-based dosimeters for *in vivo* measurements have been investigated. One of the attractive features of optical dosimetry is the potential for improved water-equivalency, compared to methods that use electrical signals. The materials considered thus far have been scintillating and optically stimulated luminescent sensors, doped and scintillating optical fibers, and radiochromic films. Several of the radiochromic films, including GafChromic MD-55 and HS, have shown a lower response for a given dose when low-energy (orthovoltage) x-ray beams were used, compared to a Co-60 source. This study continues the investigation of suitability of another radiochromic film, GafChromic EBT, for real-time *in vivo* point-based dosimetry by considering its response to a given dose delivered by beams varying in nominal energy. **Method and Materials:** 1 cm × 1cm pieces of MD-55, HS and EBT film were irradiated within a 30 cm × 30 cm × 10 cm Solid Water phantom fitted with optical fibers for real-time measurements. Each exposure delivered a dose of 100 cGy, using x-ray beams ranging in energy from 75 kVp to 18 MV. Changes in optical density (ΔOD) were compared for the three types of film across all beam energies used. **Results:** Both MD-55 and HS films showed a decrease of approximately 35% in ΔOD for a 75 kVp beam compared to a Co-60 beam. Decrease in response for 225 kVp beam was less pronounced (approximately 15%). Both HS and MD-55 exhibited this trend, confirming previous reports and validating our technique. The EBT film showed no decrease in response through the orthovoltage range. **Conclusion:** Due to a near-constant response of EBT film for a given dose delivered using 75 kVp to 18 MV x-ray beams, EBT medium is more suitable for *in vivo* measurements than MD-55 and HS films.

SU-FF-T-140

Comparison of Dose Prescription Using Single Versus Multiple Reference Points for MammoSite RTS Treatment Planning

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Purpose: To retrospectively compare dose prescription for MammoSite RTS using single versus multiple reference points through DVH evaluation. **Method and Materials:** CT images of four women treated with MammoSite RTS were selected for a retrospective study of dose prescription. The balloon was identified and contoured on the CT images using Plato BPS. A PTV was created by volumetrically expanding the balloon volume by 1cm. The final volume, PTV_EVAL consisted of the PTV minus the balloon volume. Six reference points were added along the outside edge of PTV_EVAL. Four points were added at locations lateral to the axis of the catheter, and two points were added along the axis of the catheter. Dose was prescribed to the six points individually, and DVHs of PTV_EVAL were calculated. Then dose was prescribed to 4, 5, and 6 reference points simultaneously, and a new DVH was created for each of those three cases. **Results:** For each prescription, the V150, V100, V90 and D95 from the DVH for PTV_EVAL were recorded and averaged across the four patients. When dose was prescribed individually to the two points along the catheter axis, the tissue volume receiving excess dose was unacceptable. When dose was prescribed individually to the 4 points lateral to the catheter axis, the coverage became inadequate. Plans in which dose was prescribed to multiple points simultaneously displayed sufficient coverage with lower volumes receiving excess dose. **Conclusion:** Due to the anisotropy of the source, prescriptions to individual points resulted in unacceptable coverage of the target volume or excess dose to tissue, while prescribing to multiple points simultaneously resulted in both more acceptable coverage and lower volumes of tissue receiving excess dose. Using four lateral points and one axial point resulted in the most target coverage while still limiting excess dose to tissue.

SU-FF-T-141

Comparison Of Inverse Planning Simulated Annealing And Graphical Optimization For Prostate High Dose-Rate Brachytherapy

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Purpose: HDR dose optimization may be performed using a combination of Geometric Optimization (GO) and manual adjustment e.g. Graphical Optimization (GrO), but is time-consuming. Optimization using anatomy based inverse planning e.g. Inverse Planning with Simulated Annealing (IPSA) can generate a solution in minutes. This study compares optimization using IPSA and GrO for treatment of prostate cancer. **Materials and Methods:** A retrospective comparison was performed of 63 consecutive patient plans generated and treated using GrO then re-planned using IPSA. The clinical target volume and critical organs were contoured using PLATO v14.2.6 (Nucletron). A dose of 10Gy per insertion was prescribed to the 100% isodose. Dose optimization was performed using a combination of GO and GrO. For GrO, the isodose was dragged to the desired position, and the system automatically recalculated the appropriate dwell times. For each plan, the following dosimetric comparisons were made between that generated by IPSA and that generated and treated using GrO: prostate V100, V150, V200, urethra V120, Rectal V80, bladder V80, Homogeneity Index (HI) and Conformity Index (COIN). **Results:** The V100 was slightly lower with IPSA (GrO=97.5%, IPSA=96.7% p=0.001) but with a greater reduction in V150 (GrO=35.6%, IPSA=30.2% p=0.000) and V200 (GrO=12.7%, IPSA=10.7% p=0.000). Similarly, V120 for urethra (GrO=16.1%, IPSA=6.7% p=0.000), V80 for rectum (GrO=2.1%, IPSA=1.3% p=0.000) and V80 for bladder (GrO=2.3%, IPSA=1.3% p=0.000) were significantly lower with IPSA. HI increased (GrO=0.63, IPSA=0.69 p=0.000) while COIN was lower (GrO=0.71, IPSA=0.68 p=0.000). **Conclusions:** IPSA enables the rapid generation of dose-optimized plans. The resultant plans provide comparable target coverage but with greater dose homogeneity, a lower high dose volume and lower dose to critical organs. Planning time was reduced using IPSA. This is a significant advantage over other methods of dose optimization in a clinical environment.

SU-FF-T-142

Comparison of Ion Chamber and EPID Portal Dosimetry for Dynamic IMRT QA

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Purpose: The feasibility of replacing film and ion chamber measurements for dynamic IMRT QA with EPID is investigated. Analytical corrections are explored to account for energy variation and beam hardening not accounted for in the EPID dosimetry software. **Method & Materials:** The IMRT QA process involves a qualitative check of the fluences with film and a quantitative check of the full plan with an ion chamber (a PTV and OAR point are checked). The difference must be below 5% to pass QA. The predicted and acquired dose fluences to the EPID were qualitatively compared to the predicted and acquired film fluence. Quantitative comparison of the EPID point dose to the ion chamber point dose was done by finding the percent difference between the acquired and predicted EPID point dose, and comparing it to the percent difference of the acquired and predicted ion chamber point dose at the same 3D point. Based on the difference between the predicted and acquired fluence of a test field, an analytical 2D energy response matrix was created to account for the radial energy variation of the beam. A correction based on open and closed fields that accounts for beam hardening due to leaf transmission was developed. Fourteen points were analyzed. **Results:** EPID and film measurements were equivalent. The ion chamber measurements have a 1-sigma uncertainty of 2.0%. Point dose comparisons with the standard EPID calibration gives an average difference from the ion chamber measurement of -6.09% with a standard deviation of (stdev) 3.15%. 2D energy correction gives -5.26%, stdev 3.18%. Beam hardening correction gives -1.67%, stdev 3.15%. Both corrections together give -1.46% with 2.78% stdev. **Conclusions:** The EPID system can replace film; ion chamber replacement is promising but more failure points must be tested. **Conflict of Interest:** Partial funding provided by Varian Medical Systems.

SU-FF-T-143

Comparison of Major Monte Carlo Codes in Physics Modeling and Sampling Efficiency

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Purpose: The Monte Carlo method is able to provide the most accurate radiation dose calculations. On the other hand, one issue that needs to be addressed is the reliability of the physics models in the Monte Carlo codes. The purpose of this study is to seek for a much more thorough interpretation of this issue. Methods and Materials: Several general-purpose Monte Carlo codes have already been widely used in many aspects of medical physics. Four well known Monte Carlo codes (EGSnrc, MCNP, GEANT4, and PENELOPE) are included in this investigation. The source codes are carefully studied, and the sampling techniques for each interaction for photons and electrons are evaluated in terms of accuracy and efficiency. The influence of the differences in physics modeling on radiation dose calculations is also analyzed. **Results:** All the four Monte Carlo codes present a certain extent of approximations in physics modeling, due to the lack of differential cross sections (with respect to energy and direction) and the consideration of simulation efficiency. The difference in sampled energy and angular distributions can be quite appreciable under some situations, and the difference in sampling efficiency can be significant as well. **Conclusions:** To faithfully simulate a physical interaction of radiation particles with matter with a Monte Carlo code, the physics processes have to be accurately modeled. However, the reality is that some approximations are inevitable. There are already several investigations on comparisons of the Monte Carlo codes, and both good agreements and discrepancies were reported. Since the previous studies were primarily based on simply applying the codes to some basic situations (such as PDDs and profiles in water), little in-depth understanding of the causes of the discrepancies was provided. Our investigation provides a source-code level interpretation of this issue.

SU-FF-T-144

Comparison of MLC and Solid Modulation in Pediatric Patients Receiving IMRT

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Purpose: Intensity modulated radiation therapy (IMRT) offers the potential of reducing the volume of normal tissue irradiated, and thus may provide significant benefit in pediatric patients. However, the total number of monitor units (MUs) associated with MLC-based IMRT (MLC-IMRT) may be 2-5 times higher than conventional planning, resulting in higher total body doses. Solid modulator-based IMRT (SM-IMRT) may provide significantly fewer MUs, and thus lower total body doses. The goal of this study is to compare MLC-IMRT with SM-IMRT treatment planning and delivery in the pediatric setting. Methods and Materials: Representative pediatric sites (brain, orbit, neck and abdomen) were used in this analysis. For each case, a 5-9 beam MLC-IMRT plan was generated with the XiO treatment planning system (CMS Inc., St Louis, MO) using 6 MV photons. Dose volume histograms (DVHs) were calculated and the total number of MUs was recorded. Using the same input parameters, a second plan was then generated for each patient with SM-IMRT. In both cases, 10 intensity levels were utilized. The total MUs and DVHs for the PTV and surrounding normal tissues were compared for each pair of plans. **Results:** In general, both the MLC-IMRT and SM-IMRT plans were comparable. Only minor differences in the DVHs were noted in the low dose region (20-40% of the prescription dose). However, the total number of MUs was significantly different. The average number of MUs for the MLC-IMRT plans and the SM-IMRT plans were 797 and 428, respectively (p=0.05). Measurements of the total body doses in a pediatric phantom will also be presented. **Conclusions:** SM-IMRT plans result in significantly fewer MUs compared to MLC-IMRT plans. Pediatric patients may benefit from the reduced total body doses, and hence reduced risk of secondary malignancies associated with this approach. **Disclosure:** Supported in part by CMS Inc. and .Decimal Inc.

SU-FF-T-145

Comparison of the Epson Expression 1680 Flatbed and the Vidar VXR-16 Dosimetry PRO™ Film Scanners for Use in IMRT Dosimetry Using Gafchromic and Radiographic Film

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Purpose: We have investigated the consistency of the newly available self-developing Gafchromic® EBT film relative to EDR2 for IMRT dosimetry QA when using flatbed scanner as opposing to the well established Vidar VXR-16. **Method and Materials:** IMRT plans consisting of seven to nine 6 MV beams were calculated using Pinnacle treatment planning system. The patient specific dose distributions were delivered to the phantom containing either EDR2 or EBT film. The films were scanned with both the Vidar and Epson scanners and analyzed using FilmQA™ (3cognition LLC) software. Comparisons between measured and calculated dose distributions are reported as dose difference (DD) (pixels within ±5%), distance-to-agreement (DTA) (3 mm), as well as gamma values (dose difference = ±3%, distance=2 mm). **Results:** Our preliminary analysis of 9 IMRT cases showed that: (i) Vidar and Epson EBT scans differ on average by 7.2% for DD, 6.3% for gamma, and 8.6% for DTA; (ii) same comparison using EDR2 gives 2.2% for DD, 3.1% for gamma, and 2.2% for DTA; (iii) the Epson EBT and EDR2 scans differ on average by 3.4% for DD, 5.0% for gamma, and 2.9% for DTA; (iv) the same comparison between EBT and EDR2 films using Vidar gives 10.3% for DD, 6.8% for gamma, and 5.1% for DTA. **Conclusions:** Tissue equivalence, high spatial resolution, energy independence, and self developing properties make the choice of EBT film for IMRT QA more desirable and cost effective than silver based radiographic film. Much better agreement with calculations can be obtained using EBT with a flatbed scanner. While both scanners give equivalent results with EDR2 films, a flatbed scanner in transmission mode is recommended to achieve optimal results with the EBT films.

SU-FF-T-146

Comparison of the Gliasite Radiation Therapy System (RTS) with Intensity Modulated Radiation Therapy (IMRT) for Intracranial Tumors

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Purpose: To compare the Gliasite Radiation Therapy System (RTS) to intensity modulated radiation treatment (IMRT) with respect to dose distribution to both the tumor bed and to critical structures. **Method and Materials:** At our institution, between January 2002 and January 2005, 30 patients were treated with the Gliasite RTS. A group of 20 patients for whom magnetic resonance imaging (MRI) studies were available was selected out of this sample. Patients were originally treated with the Gliasite RTS to a dose of 6000 cGy prescribed to 1 cm beyond the periphery of the balloon catheter and delivered over 6 days. Utilizing MRI studies with the balloon catheter in place, the same patient group was then planned for IMRT, and the dose distributions to the tumor bed and to critical structures were compared. **Results:** The range of Gliasite RTS balloon catheter sizes was 4-35 cc. The range of source activities was 154.2 – 418.8 mCi. The Gliasite RTS delivered significantly less dose to the 50% volumes of critical structures versus IMRT. IMRT delivered significantly more dose to the clinical target volume (CTV) at the 100% (4936 vs. 4351 cGy, p=0.02), 99% (5725 vs. 5083 cGy, p=0.001), and 95% target volumes (6052 vs. 5723 cGy, p=0.03) versus the Gliasite RTS. There was no significant difference between IMRT and the Gliasite RTS with respect to the dose delivered to the 90% volumes of the CTV. **Conclusion:** The Gliasite RTS consistently provided more sparing of critical structures compared to IMRT for intracranial tumors. However, IMRT delivered a higher dose to the CTV that more closely approximated the prescribed dose. The choice of treatment modality must be weighed between the desire to protect normal tissue and the need to maximize dose to target volumes.

SU-FF-T-147

Comprehensive Cyberknife QA-A 2 Year Experience

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Purpose: The 6MV X-band robot mounted linac in a CyberKnife(CK) system is more compact and maneuverable than conventional S-band linacs. Long term mechanical and radiation output stability of this linac is crucial for the sub-millimeter accuracy needed for stereotactic radiosurgery (SRS). The versatility of the CK allows for both extracranial and intracranial SRS use. The synchrony system tracks patient breathing thereby enabling precise irradiation of moving tumors. We evaluate the mechanical and radiation stability of the CK and the targeting error of synchrony with respect to variations in simulated anterior-posterior(AP) motion using a ball-cube phantom inside which gafchromic film is orthogonally positioned. **Methods and Materials:** CK output is monitored by a vented chamber unlike a sealed chamber used in conventional linacs. A daily calibration factor(CF) is obtained to correct for the changes in temperature, pressure and output .Absolute output, flatness, symmetry penumbra ,End-to-End and Iso-post tests are done monthly to verify the accuracy of the dose distribution and alignment of the X-ray tube and detectors respectively. A 2D motion platform was fabricated to simulate respiration. The amplitude of motion ranged between 1cm and 3cm, a dose of 3000cGy from a 3 path fiducially tracked plan were given to the phantom at the 62% iso-dose line The films were analyzed using End-to-End software and the total targeting error in the AP direction was determined. **Results:** Over two years of clinical use the linac output variation decreased steadily from 2% to below 1% while flatness, symmetry, and penumbra were well within CK specifications. The averaged CF was 1.011±0.008MU/cGy, the static targeting error was 0.8 ± 0.047mm and the synchrony targeting error was 1.63±0.056mm.**Conclusion:** We conclude that the CK mechanical system delivers the required targeting accuracy in both synchrony and static treatments, while the radiation instability is less than 2 %.

SU-FF-T-148

Cone-Beam Reconstruction (CBR) Using a X-Ray Simulator in Intracavitary Brachytherapy

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Purpose: There are few limitations in conventional CT for localizing the dummy sources due to the slice image which has a certain distance between images. The use of the cone-beam CT in brachytherapy also has limitations because of the economical efficiency in brachytherapy fields. To overcome former problems, we performed the CBR using x-ray simulator. **Method:** The home-made anthropomorphic pelvic phantom with the localizer and the HDR applicator set was simulated on the digital x-ray simulator. The images were obtained with 10 degree intervals, and the CBR performed in the limited projections (36, 18, 12, 9 projection). The coronal planes (anterior-posterior views) of CBR were mainly used for evaluating a CBR results. **Results:** We could obtain the CBR images with dummy source and artificial anatomic structure in the phantom. The peak pixel intensity and size differences of the dummy sources, which were important factor to distinguish the dummy sources from the backgrounds in coronal planes, were compared with each CBR results of the limited projections. **Conclusions:** We present the method for accurate source localization in a substitution for cone-beam CT. This CBR approach provides the exact position of the sources and the delineation of approximate organ structure in brachytherapy planning, thus it could be a useful and economical technique for improving the planning results.

SU-FF-T-149

Conformal Vs. IMRT Concomitant Boosts for IMRT Based Head and Neck Treatment

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Purpose: To evaluate conformal 3D-CRT and IMRT techniques for the boost portion of a concomitant boost treatment schedule for IMRT based head and neck radiation. **Method and Materials:** Nine-field IMRT plans were generated using Eclipse for 4 stage IV oropharynx patients, treating all target volumes initially to 57Gy. Two alternative plans were then generated to deliver a 15Gy boost to gross disease: a 3D conformal plan, using 3-4 fields, and 5-field IMRT plan. Boost volumes ranged from 25-60cc. The IMRT and 3D-CRT boost plans were evaluated as individual graphic plans and as a cumulative with the first course treatment for a total dose of 72Gy (IMRT/IMRT and IMRT/3D-CRT combinations). The comparison assessed target coverage, dose to critical structures (parotids, cord and oral cavity), hot spots and number of monitor units (MU). **Results:** Evaluated as a cumulative plan the IMRT/IMRT technique met all the constraints for critical structures (mean dose to parotid 26Gy, cord max 46Gy) and the hot spots were between 104-106%. The IMRT/3D conformal technique also met the constraints for the critical structures with hot spots between 103-105%. Both cumulative plans achieved 98.6-100% coverage of boost volumes. Evaluated as individual plans both the IMRT and 3D conformal boost plans achieved the desired coverage while keeping the dose to critical structures at a minimum; hot spots were located within the confines of the boost volume. The number of MU's ranged from 250-296 for the 3D-CRT plan in comparison to 360-562 for the IMRT. Average planning time was 1.0 and 2.5 hours for the IMRT and 3D-CRT boost, respectively. **Conclusion:** Both boost techniques are dosimetrically equivalent. Treatment technique can therefore be chosen based on the available clinical recourses

SU-FF-T-150

Consequence of CT Couch Sag in Radiation Therapy

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Purpose: To characterize couch sag on a CT scanner and determine the impact on patient treatments. A CT couch sags as it enters the gantry, and the amount depends on couch design, material, patient weight and distribution. **Method and Materials:** Four individuals were placed on a CT scanner couch (GE Discovery Lightspeed). A dial indicator was fixed to the bore of the CT scanner to measure couch deflection at the scanning plane when the couch was extended to various lengths. A second experiment was performed to measure sag at various positions for a fixed couch extension. A steel I-beam with the dial indicator mounted on a rail was placed underneath the CT and tomotherapy couches. Two uniform loads were placed on the couch for three couch extensions and measurements were recorded at discrete locations. **Results:** Two forms of couch sag relevant to radiotherapy were observed: absolute and intra-target sag. Absolute sag was shown to be 8.0±0.5 mm. Intra-target sag depended on the S-I length of the target and could be 2.3±0.5 mm. Both CT and tomotherapy couches displayed similar sag patterns. Differences in sag between the couches were more pronounced at short cantilevered distances with a maximum difference of 1 mm. **Conclusion:** A significant amount of sag occurs at the scanning plane resulting in a shearing of the images used for treatment planning. Absolute sag may be corrected by a couch height adjustment but intra-target sag is a concern for elongated targets. The impact of sag on tomotherapy treatments is minimal since the relative difference in sag patterns between CT and tomotherapy couches is small. However, differences between CT and tomotherapy couch sag have become a concern for facilities treating total marrow irradiation (TMI) fields with tomotherapy. **Conflict of Interest:** Mackie has a financial interest in TomoTherapyInc.

SU-FF-T-151

Conservation of Integrated Reference Air Kerma

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Purpose: To demonstrate the conservation rule of the integrated reference air kerma (IRAK). **Method and Materials:** For a brachytherapy photon source whose radial dose functions is flat over the clinical distance range, the dose falls off with the inverse square of distance. If we assume further that the photon spectrum does not change with distance in tissue and the kerma in tissue can be substituted for radiation dose, it follows that both the photon particle and energy fluences obey the inverse square law. Under these assumptions, the photon fluence integrated over any arbitrary isodose surface, which is proportional to the integrated reference air kerma (IRAK), is conserved as long as the isodose surface contains all the brachytherapy sources, regardless of the distribution of the activity or equivalently the shape of the isodose surface. **Results:** One application of this conservation law is that the total dwell time (proportional to IRAK) of a plane implant is proportional to the total area of the prescription dose isodose surface. A quick second check QA program is established based on this relation for our intra-op HDR using HAM applicator. Another application is to calculate the area of the absolute isodose surface assuming all the distributed activity is placed on one single point. The total area of spherical isodose surface is simply AREA = $4\pi r_0^2 \Lambda ST/D$, where r_0 is the reference radial distance of 1 cm, Λ the dose rate constant, S the source activity, T the total dwell time, and D prescription dose. This area should equal the isodose surface area for an plan with optimized dose distribution achieved by redistributing the same amount of activity within tissue. Two examples, one HDR planar implant and the other Patterson-Parker nomogram, are given in the supporting material. **Conclusion:** The IRAK conservation rule has both theoretical and practical values.

SU-FF-T-152

Convolution/superposition Algorithm and High-Z Dental Materials: Dosimetric Study in a Solid Water Slab Phantom

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Purpose To address the accuracy of the dose calculated with convolution/superposition algorithm in the presence of high-Z dental materials. **Methods and Materials** Three methods were utilized to access the dose: convolution/superposition algorithm, Fluence Map Monte Carlo (FMMC) method, and radiochromic film. We considered a solid water® slab phantom which had an embedded high-Z material. For dose calculations and measurements we used a 6MV photon beam from a clinically commissioned linear accelerator. **Results** We observed a close agreement for the dose measured with radiochromic film and the dose calculated with FMMC algorithm. On the other hand, a large discrepancy was discovered for the dose calculated with the convolution/superposition algorithm compared to the dose obtained with measurement or FMMC algorithm. The greatest discrepancy was observed downstream from the high-Z cerrobend inhomogeneity where the convolution/superposition algorithm calculated a dose which was higher than the dose measured with radiochromic film by 10-20% depending on the size of and the distance

from the inhomogeneity. Clinically this finding shows that the delivered dose would be 10- 20% less than the prescribed dose which was calculated with convolution/superposition algorithm. In the region upstream from all the studied high-Z inhomogeneities the convolution/superposition algorithm was underestimating the delivered dose. The convolution/superposition algorithm was unable to properly estimate the dose enhancement due to the increased backscatter near the inhomogeneity. **Conclusions** The convolution/superposition algorithm may significantly overestimate the actual dose in the site of the tumor located downstream from the high-Z dental restorations or prostheses.

SU-FF-T-153

Correlation of ICRU Reference Dose and PTV Dose Descriptors in Intensity Modulated Radiation Therapy

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Objective: The application of IMRT in clinical trials has been hindered by a lack of internationally accepted standards for prescribing dose as in 2D and 3DCRT external beam planning. We aimed to study the relationship of ICRU reference dose to mean, median, and modal PTV doses for IMRT applied to diverse targets. **Materials and Methods:** DMLC-IMRT plans for 70 patients treated for prostate (14), gynecological (19), head and neck (19), lung (4), rectal/anal (8), brain (4) and abdominal disease (2) were randomly selected and analyzed. The ICRU reference point was located in each plan following ICRU report 50 and 62 guidelines. The ICRU reference dose, PTV mean, median, and modal doses, and DVHs were calculated with an Eclipse treatment planning system (Varian). PTV range was 50 – 1937 cc. Median PTV was 508 cc. **Results:** In general, ICRU reference dose was > PTV mean dose (in 82% of the cases studied). The difference between the PTV mean and the ICRU reference doses was 2% or less in 77% of the cases studied (mean difference -0.73%, range -4.2% to +3.6%). The ICRU reference dose and the PTV median and modal doses were not significantly different (p = 0.3 and 0.15 respectively). **Conclusion:** The ICRU reference point dose for the IMRT described herein appears to be reflective of PTV median or modal doses but does not represent PTV mean dose. New dose specification standards for IMRT, consistent with methods used to accredit facilities to apply IMRT in clinical trials, may enhance the quality of these trials and of other trials using rapidly emerging radiation planning and delivery techniques.

SU-FF-T-154

Cumulating Static Dose Distributions to Simulate Dynamic Dose Distributions: An Experimental Study

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Purpose: To quantify the change of the beam penumbra when irradiating a moving object. To compare dose distributions from irradiated films of an inhomogeneous moving phantom with cumulated static dose distributions (SDD) obtained from the TPS. **Method and Materials:** A cubic inhomogeneous phantom ("tumor in lung"), consisting of a polyethylene insert embedded in a wood phantom, was used for the study. This phantom was set on a "dynamic" plate which simulated respiration. This plate had a vertical excursion of 2cm with a 4s period. X-OmatV films were placed at the center of the insert. They were irradiated perpendicularly to the direction of the movement with a 6MV photon beam of 8x8cm^2. The movement of the plate was split in 4 intervals of positions. For each position interval, the duration was determined according to the sinusoidal model. SDD were calculated for the different positions of the moving phantom with the superposition convolution algorithm of the Xio TPS. Dynamic dose distributions (DDD) were simulated by summing SDD weighted with the temporal weight. Simulated DDD from films or from the TPS were finally compared with the measured DDD. Penumbrae were measured from dose profiles at the center of the phantom. **Results:** For a motion amplitude of 2cm, the penumbra increased with a factor of 2.7 while penumbra from calculated dose distributions increased with a factor of 2.4.**Conclusion:** This preliminary study aims at personalizing margins in lung treatments.

SU-FF-T-155

Derivation of Photon Energy Spectra From Transmission Measurements Using Large Fields

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Purpose: To reconstruct a 6 MV photon spectrum using an iterative process based on attenuation measurements performed in large fields. **Method and Materials:** The main algorithm written in Mathematica® code uses as input data Monte Carlo-predetermined pencil beam monoenergetic scatter kernels for various water phantom thicknesses, open beam fluences and beam fluences measured in air with phantoms of different thickness. The iteration starts with a flat spectrum used to calculate the polyenergetic kernels for each water thickness. The scattered radiation is calculated by convolving open beam fluences with the corresponding polyenergetic kernels. The primary fluences are determined by subtracting the scatter fluences from the fluences measured with the phantom in place. The reconstructed primary energy spectrum is derived from the transmission values using the simulated annealing technique. The spectrum determined at the end of the loop is compared to the input spectrum of the main algorithm. If the new spectrum does not meet the stopping criterion, it is fed as input for a new iteration. **Results:** 72 data Monte Carlo monoenergetic scatter kernels are derived for six water thicknesses. The amplitude of the monoenergetic scatter kernels increases with energy and water phantom thickness. For thin phantoms there is a strong dependence of scatter with thickness. For large phantoms the increase is negligible after a certain phantom thickness which depends on beam energy. The average energy of the derived spectrum is 1.9MeV. There is a good agreement (2%) between measured and calculated PDD except at the first portion of the graph (electron contamination from head is not account for).**Conclusion:** The method is robust, good for portal dosimetry. It can be used to evaluate accurately the photon scatter in portal imaging since is taking into account the energy spectrum dependence of the scatter.

SU-FF-T-156

Determination of Skin Dose for Modulated Electron Radiation Therapy (MERT)

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Purpose: Estimation of surface dose is very important for patients undergoing radiation therapy. This work is aimed at accurate determination of the dose to the skin at a depth of 0.07 mm, the practical reference depth for skin as recommended by ICRP and ICRU, using ultra thin TLDs, parallel ion chamber and Monte Carlo calculations for patients undergoing energy modulated electron radiation therapy (MERT). **Method and Materials:** Monte Carlo simulations and measurements were carried out for 5x5 cm^2 and 10x10cm^2 fields for electron beams of energies ranging from 6 to 21 MeV. The dose at the ICRU reference depth was computed at normal incident angles. For patient undergoing MERT treatments, the SSD to the patients skin is 60cm and the treatment is delivered with the photon MLC. Finally, the dose was measured and calculated for breast MERT plans using the leaf sequence obtained for each case. **Results:** Good agreement (±3%) was achieved between measurements and calculations. The surface dose at the entrance was increased as the electron beam energy and/or the field size increased. A decrease of the surface dose is observed when the SSD is smaller. The surface dose at 60cm was measured to be 1-4% lower than the one at 100cm SSD. The surface dose was increased under MERT conditions proportional to the modulation in MU of the treatment. **Conclusions:** The dose at the surface of the patient is mostly dependent on the SSD, the electron beam energy and modality. By correlating the TLD measurements to Monte Carlo calculations, one can predict the dose at the skin surface with great accuracy. Knowing the dose received at the surface of the patient can lead to prediction of skin reactions helping with the design of new treatment techniques and different dose fractionation schemes.

SU-FF-T-157

Determination of the Effective Chamber Position of 2D Ion Chamber Array Using An HDR Afterloading Device

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Purpose: Detector arrays are useful devices for quality assurance (QA) since they can record and display 2D data in real time, thus replacing film for many QA procedures. We have carried out tests on one such device*. **Methods & Materials:** This device consists of 1020 ion chambers, 4.5 mm in diameter, 5 mm high and 7.6 mm center to center. This 32x32 chamber array is located at some depth below the surface of the surface of the container. To determine the effective depth of the chambers below the surface, experiments were carried out using a 4 MV linac and an HDR afterloading device with a ^{192}Ir source. For the linac, measurements were made at distances between 80 and 135 cm, in 5 cm steps. For the afterloading device, a special jig was made that permitted placement of the catheter holding the source at distances from 1 to 10 cm at 1 cm steps. Plots were made of the inverse root of the charge collected vs. the distance from the top of the detector. **Results:** The inverse square law was found to be valid in both cases (r^2 = 0.9994 [linac] and 0.9998 [HDR]). The linac experiment indicated that the effective distance of the chambers below the surface was –1.9 ± 0.9 cm, while for the HDR experiment it was –0.62 ± 0.03 cm. Thus the error for the HDR measurement is considerably less than for the linac measurement. This is clearly due to the fact that the linac data has to be extrapolated over a large distance, leading to a greater uncertainty. **Conclusions:** Use of a ^{192}Ir afterloading source has enabled the effective chamber position of a 2D ion chamber array to be determined to an accuracy better than 0.5 mm. *MatriXX (Scanditronix-Wellhofer, Bartlett, TN) (Research sponsored by Scanditronix-Wellhofer GmBH)

SU-FF-T-158

Determination of the Energy Spectrum of Bremsstrahlung of Linear Accelerations by Monte-Carlo Calculations and An Analysis of Depth Dose Curves

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Purpose: The knowledge of the bremsstrahlung spectrum of a linear accelerator (6 MV up to 18 MV) represents the physical base of therapy planning systems. It is obtained by Monte-Carlo calculations by taking account of the complete beam-line (geometry/materials). It is also obtained by an analysis of depth dose curves of small fields via Laplace transform, if the electron energy E_{el} is known (upper limit of photon energy). **Method and Materials:** Monte-Carlo calculations with EGSnrc with respect to the beam-line of 6/18 MV (Varian 2300 C/D) and 6 MV (Varian 600C) have been performed for the AAA algorithm (Eclipse). The analysis of absorption depth dose curves in water (3x3 cm^2 / 4x4 cm^2 fields) of the mentioned machines has been performed for the central ray and tilted rays with the Laplace transform of a power sequence of Poisson distributions, which provide the reproducing kernel and the energy spectrum. The scatter profiles have been removed by a deconvolution. **Results:** Monte-Carlo calculations and the Laplace transform method are in good agreement (standard deviation: ca. 1%) in the above cases. The formal integration of the reproducing kernel provides an analytical spectral distribution function

$$f(E) = (1-\exp(-\alpha \cdot E / E_{el})) \cdot \exp(-\beta E^2 / E_{el}^2) \cdot (1-E/E_{el})^q$$

The parameter α and q depend on the radial distance of tilted rays from the central ray at surface. It is also used to fit fluctuations of Monte-Carlo calculations. **Conclusion:** The Laplace transform method even works, if only E_{el}, the measured depth dose curves and profiles of small field sizes are known. A comparison of 6 MV (2300 C/D) with 6 MV (600C) shows that the spectral distribution of the latter case rather corresponds to the 10 MV mode of a 2300 C/D machine. This results from the Pb-alloy of the flattening filter, whereas the 6/10 MV modes of the 2300 C/D use a Cu-filter.

SU-FF-T-159

Determination of the MLC Scatter, MLC Transmission and Dosimetric Gap in Dynamic IMRT as a Function of Field Size, Depth and Beam Energy

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Purpose: To develop a dynamic MLC test for the determination of the MLC scatter, transmission and dosimetric gap for large field size and complex geometry IMRT. **Materials and Methods:** A series of dynamic MLC tests was designed and performed with ionization chamber in a solid water phantom as a function of field size, depth, MLC gap size for 6,10MV 2100Ex: open beam (OB), closed MLC (cMLC), and dynamic sweeping gap (dMLCgap). Based on a generalized fluence model, MLC scatter, direct MLC transmission (no scatter) and dosimetric gap (due to rounded leaves) were determined. IMRT planning system predictions and measurement doses were compared at the central axis and outside of the field edges. Dose errors were corrected using the generalized fluence model. **Results:** MLC scatter is responsible for field size dependence of cMLC-to-OB dose ratio (1.45% for size=5cmx5cm, 1.8% for size=14cmx30cm, 6MV). MLC scatter is rather uniform within and outside of the field edges, and decreases only slightly with depth. Direct MLC transmission (no MLC scatter) changes with depth up to 10% (6MV), 5% (10MV) due to beam hardening. In dynamic MLC delivery, MLC scatter is significant for large field sizes (14cmx30cm) and low average fluence $\langle\phi_{dMLC}\rangle$: MLC scatter=1%-5% for clinically realistic $\langle\phi_{dMLC}\rangle$ =30%-10%, ($\langle\phi_{OB}\rangle$=100%, $\langle\phi_{cMLC}\rangle$ ≈1.5% by definition). Dose errors of 1%-8% for large sizes and sweeping gaps 1.0cm-0.1cm were corrected when the modified fluence model (including MLC scatter) was used instead of the Eclipse fluence. **Conclusions:** Many commercial IMRT planning systems do not account for the MLC scatter. It is suggested that the OB-cMLC-dMLCgap test be used for commissioning of the IMRT when field sizes are large and average fluence $\langle\phi_{dMLC}\rangle$ is low. MLC parameters in IMRT planning system may need to be adjusted separately for each IMRT class depending on field size and fluence complexity (or $\langle\phi_{dMLC}\rangle$).

SU-FF-T-160

Development and Use of a Dose-Volume Histogram Analysis Tool

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Purpose: To develop an automated tool providing rapid, consistent analysis of the dose-volume histograms (DVH) generated by commercial treatment planning systems (TPS). This tool has been used for comparative analysis of competing plans and is currently being used to study and mimic physician decision criteria. **Method and Materials:** Software was developed to import DVH information stored in RTOG submission format, making it relatively independent of the TPS used to generate the plan. Analysis tools are provided to generate conformity, uniformity and radiobiological quantifiers which describe each treatment plan. These quantifiers are presented separately and as overall plan evaluation values, to include CTI, CN and COIN. Radiobiological quantifiers include NTCP, EUD and EUBED. **Results:** The software has been used to evaluate competing techniques—(1) conventional, (2) two-field tangential inverse-planned IMRT and (3) multiple (3 or more) beam IMRT--of breast irradiation on 20 patients. Plans were adjusted to provide 90% of the prescription dose, 50.4 Gy in 28 fractions, to 90% of the PTV. The superiority of the dose distribution of the IMRT methods was clearly demonstrated as more conformal (CN 0.79 vs. 0.83, $p < 0.001$) with reduced doses to the lung (mean dose 5.4 Gy vs. 4.6 Gy, $p = 0.004$) and heart (mean dose 2.3 Gy vs. 1.5 Gy, $p = 0.02$). The radiobiological advantages of IMRT, although better, were less dramatic (EUD, not significant, NTCP effective volumes significant, but NTCP too small to draw conclusions). **Conclusion: :** Use of this tool enables easy, consistent interpretation of the DVH and the overall treatment scheme. Choosing between competing plans, developing and adjusting dose limits and weighting used in objective functions, and the ability to describe and mimic the physician decision making process are possible uses of the tool.

SU-FF-T-161

Development of a More Objective and Accurate Film Verification Tool for Stereotactic Radiosurgery

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Purpose: To develop a more objective and accurate quality assurance (QA) tool for use in spatial verification of patient treatment isocenter(s) to be used in conjunction with a commercial linear accelerator based stereotactic radiosurgery (SRS) system. **Method and Materials:** A plastic positioning device was constructed to house an open-ended cylindrical lead foil ring approximately 0.3 [mm] thick and 1.0 [cm] in diameter. The cylindrical design was used for comparison versus the vendor supplied radio-opaque ball design. Verification films were acquired using a 1.75 [cm] SRS cone with the same set-up used for a SRS patient treated at our clinic. Films were acquired at gantry angles of 0°, 90°, and 270° for both the radio-opaque ball and cylindrical device and repeated three (3) times. The objectivity of the film QA evaluation was determined by calculating the variance in the measurement of the radial offset distance for each gantry angle. In addition, five (5) additional sets of verification film data were acquired to evaluate the detection of a range of deliberate erroneous incremental offsets (0.0, 0.5, 1.0, 1.5, and 2.0 [mm]). The accuracy of the film QA evaluation was determined by measuring the isocenter offsets in the QA films and comparing those results to the known offset using linear regression analysis. **Results:** Calculated variance values from the QA films acquired at three (3) gantry angles measuring radial offset showed a reduction in user variability from 28% to 21% when the cylindrical device was used. Similarly, linear regression analyses of the incremental offset QA films demonstrated a slightly better correlation to the expected values when using the cylindrical device. **Conclusion:** The cylindrical SRS positioning device improves the objectivity of the QA procedure for isocenter verification and detects critical set-up errors more accurately thus improving the ability of the physicist to assess patient set-up.

SU-FF-T-162

Development of a Patient-Specific Lung Phantom Using 3D Imaging and Rapid Prototyping

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Purpose: Physical human phantoms have been widely used in verification of external radiotherapy treatment plans, study of exposures outside of the target regions, and calibration of whole-body counter for nuclear medicine procedures and for radiation safety bioassays. Existing phantoms are mostly crude in anatomical representations, although realistic 3D images of patients are available. This paper presents a method of fabricating a physical phantom of the lung using patient-specific medical images and computer aided design (CAD) and manufacturing (CAM). **Methods:** Medical images have been used to construct the VIP-Man model from Visible Human images. The voxelized data from the lung of VIP-Man were translated into 3D polygon mesh models. The models were then corrected and scaled to the actual size of the organ. A 3D rapid prototyping machine (i.e., a 3D printer) was used to develop a physical mold of 3D polygon mesh lung. The mold was filled with lung tissue-equivalent foam, which matched the density and effective atomic number of the lung tissue. **Results:** Using the methods described above the lung of the VIP-Man model in STL format was used to fabricate an identical 3D tissue-equivalent phantom. **Conclusions:** A method has been developed to rapidly prototype physical lung phantoms using CAD and CAM capabilities. Currently, there is no method that automates this complicated process of creating 3D organ phantoms. A major research effort in this task is to develop an integrated software method that will streamline image processing and 3D printing.

SU-FF-T-163

Development of An Inverse Optimization Package for Non-Uniform Dose Distribution Based On Spatially Inhomogeneous Radiosensitivity

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Purpose: To develop an inverse optimization algorithm that is capable of generating non-uniform dose distribution with sub-regional dose escalation based on spatially inhomogeneous radiosensitivity in the target, while keeping the critical structure doses as low as possible. **Method and Materials:** A matlab package with GUI was developed. The software system reads in structure contours, reference 3D-dose distribution (e.g., conventional uniform dose), dose to each voxel from all beamlets, as well as the voxel radiosensitivity from biological images. This system is able to optimize beamlet weights based on sequential quadratic programming (SQP) method to achieve maximum equivalent uniform dose (EUD) for target and minimum EUD for critical structures. The beamlets were generated using a commercial planning system (XiO, CMS). The EUD was calculated based on 3D-dose distribution and spatial radiosensitivity distribution which is extracted from biological images. Constraints that limit the doses to critical structures not to exceed the corresponding maximum for the reference plan are applied. Sample spatial radiosensitivity distributions based on physiological MRI of brain tumor were used to test the developed system. DVHs and EUDs for the uniform and non-uniform dose distributions are compared. **Results:** Using the newly develop system, we have generated non-uniform 3D-dose distributions for selected patient cases. Sub-regional dose escalation can be as high as 30% of the uniform dose as planned conventionally. The target EUDs are found to be higher than those for the uniform dose planned ignoring the spatial inhomogeneous radiosensitivity. The EUDs for organs at risk are found to be equal or lower than those for the uniform dose plans. **Conclusion:** We have developed a package that is capable of generating non-uniform dose distributions optimized for spatially inhomogeneous radiosensitivity. Sub-regional dose escalation may lead to increased treatment effectiveness as indicated by higher EUDs. The current development will impact biological image guided radiotherapy.

SU-FF-T-164

Development of Method to Visualize I-125 Seed in Postimplant Seed Identification in Prostate Permanent Implant Brachytherapy.

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Purpose: We investigated the method to visualize I-125 seeds in CT-based postimplant seed identification in prostate permanent implant brachytherapy using CT sinogram. Furthermore, we evaluated the impact of manual seed identification using our method on dosimetric parameter compared with automatic seed identification of commercially available planning system. **Method and Materials**: The reprojected CT sinogram was used to visualize I-125 seeds. CT images of the metal parts only were separated from the original CT images by setting the threshold for pixel value. Then we performed edge detection. Using these images, sinograms of CT images with and without seeds were obtained by inverse Radon transform, and the sinogram of the metal image was subtracted from that of the original image. Finally, the image was reconstructed using the sinogram by Radon transform. The phantom study was performed to verify whether our method can separate adjacent seeds correctly. For patient study, postimplant analyses of 10 patients were performed. The implanted seeds were identified both by manually using our method and automatically using Variseed auto seed finder system. The differences of the number of seeds, dose delivered to 90 % of prostate volume (D90), and D5 of urethra between two methods were investigated. For statistics, paired t-test was performed. **Results:** In phantom study, even two adjacent seeds were clearly separated by our method but not by automatic seed finder. For patient study, the number and orientation of seeds could be clearly determined. In post implant dosimetry, significant differences were observed between our method and automatic seed finder in seed number ($p=0.009$) and D90 of prostate ($p=0.028$). **Conclusion:** Although our method can only be applicable in manual seed identification, it can be useful in postimplant dosimetry in clinical practice.

SU-FF-T-165

Development of Web-Based Customized Cancer Radiation Treatment Planning Simulation System

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Customized cancer radiation treatment planning for each patient is very useful for both a patient and a doctor because it makes possible for the most effective treatment with the least possible dose to patient. Radiation

planners know that too small a dose to the tumor can result in recurrence of the cancer, while too large a dose to healthy tissue can cause complications or even death. The best solution is to build an accurate planning simulation system to provide better treatment strategies based on each patient's computerized tomography (CT) image. We are developing a web-based customized cancer radiation therapy simulation system consisting of three important computer codes; the parallel Monte Carlo high-energy beam code (PMCEPT code) for calculating doses against the target generated from the patient CT image, the parallel mixed integer linear programming code for optimizing the treatment plan, and scientific data visualization code for efficient pre/post evaluation of the results. This independent system with a Beowulf PC cluster of about 100 CPUs is operated by the client-server system via web because managing a big PC cluster and continuous updating of the complicated MC and optimization codes are not an easy job for a hospital. Another benefit for an independent client-server system is to provide high quality results to many hospitals, which will eventually lead to decrease the medical cost and provide high-quality medical service to local area hospitals. At the conference, we are going to introduce the idea and progress of this project. This work was supported, in part, by the SRC/ERC program of MOST/KOSEF (grant number: R11-1999-054).

SU-FF-T-166

Different Method of IMRT Planning for Breast Treatment

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Purpose: To compare three different methods of IMRT planning for breast treatment. **Method and Material:** Breast IMRT plans are conducted for several Patients using Pinnacle PHILIPS system. Three IMRT methods have been utilized; the first is Forward Planning (FP) technique using segment weight optimization for selected set of objectives such as GTV, PTV, lung, heart, etc. The second method is Inverse planning (IP) technique using Direct Machine Parameters Optimization (DMPO) with same objectives used in FP plus an extra segment to account for flash .The third is IP technique using DMPO with same objectives used in FP plus an extra objective called "Flash Planning Target (FPT)" defined by expanding the PTV by 2.5-3.0 cm in the interior direction of the breast depending on the required amount of flash. The "FTP" objective is defined as a uniform dose with 80% or higher of the prescribed dose with an extremely minimum dose in the order of 1E-15. "FPT" objective is included in the DMPO to generate sufficient flash (due to breathing parameter) which could not have happen without including this objective in the IP optimization. Comparing all methods, IP technique using the two DMPO methods will allow having a Flash for most of the treatment without defining segments and they will give better coverage of the breast from the superior and inferior direction with better controlling the dose to the surrounding organs. **Results:** Using the "FPT" objective along with DMPO techniques provide the open segment higher percentages for each beam with some other segments generated by Pinnacle not by the planner are superior over FP method. **Conclusion:** Inverse planning techniques using DMPO technique mentioned above will give a better coverage of the breast from the superior and inferior direction with better controlling the dose to the surrounding healthy tissues.

SU-FF-T-167

Digital Data Integrity QA for Multi-Institutional Clinical Trials

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Purpose: The Image-guided Therapy QA Center (ITC) as part of the NCI-sponsored Advanced Technology QA Consortium (ATC) has nearly 15 years experience in performing data integrity QA review for multi-institutional advanced technology clinical trials that require digital data submission. This presentation will report on that experience. **Method and Materials:** Participants in some advanced technology multi-institutional clinical trials must be able to submit imaging data as well as RT objects (CT, RT Structure Set, RT Dose, and RT Plan) to the ITC for protocol compliance QA review of contoured volumes and dose coverage/heterogeneity. Data are sent via FTP or on media. However, prior to that QA review, experienced personnel at the ITC carefully review each digital data set in regard to completeness of protocol required elements, format of data, and possible data corruption. **Results:** Thus far over 3000 data sets have been submitted to ITC. Unfortunately, data often need resubmission due to problems discovered by ITC. Errors in submission can be divided into five categories: 1) misuse of UI of treatment planning system (TPS), 2) misunderstanding of protocol requirements, 3) non-uniformity of DICOM export implementations by TPS vendors, 4) user error with digital data transfer software, and 5) updated TPS software, whose data export feature no longer is ATC compliant. Statistics of number of resubmissions required as well as specific details of these problems will be presented. **Conclusion:** Digital data submission of complete 3D data set is essential for QA of advanced technology clinical trials. However, collection of these data requires review and troubleshooting by experienced personnel to ensure subsequent protocol compliance QA and later still, quality data analysis. A significant portion of the ITC workload involves digital data integrity QA to ensure quality of submitted digital data. Support: NIH U24 Grant CA81647

SU-FF-T-168

Does IMRT Planning Increase the Effect of Systematic Patient-Beam Positioning Uncertainties On the Rectal DVH Compared to Conformal Planning?

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Purpose: The goal of this study is to compare the effect of systematic patient-beam positioning uncertainties on the rectal DVH between IMRT and conformal planning and to validate the use of the dose constraints V95%, V90%, V75% for plan evaluation. **Method and Materials:** For a selected prostate case, a 47 segment IMRT plan, with five equally spaced treatment fields, was produced using the XiO treatment planning system (v4.02, CMS, St Louis). Additionally, a further two conformal plans, with three and four treatment fields respectively, were produced using the Addenbrooke's Radiotherapy Planning System (ARPS). In order to simulate the patient-beam positioning for all plans identically, the XiO plan was imported into ARPS. Patient-beam positioning errors were simulated in ARPS by shifting the treatment isocenter by 5 and 10 mm superior, inferior, left, right, anterior and posterior. For every isocenter position the resultant dose distribution and rectal DVH was calculated without altering the beam configuration or beam profiles. **Results:** The effects of patient-beam positioning uncertainties are found to be significant when the isocenter is shifted along the A-P direction. The rectal V95% for the unshifted plans was smallest for the IMRT plan. However, a 5mm posterior shift increases the V75% (55.5Gy) by 11.5% for the IMRT plan. This compares with increases of 10.1% and 10.6%, for the 3-field and 4-field plans respectively. In the higher dose region V90% (67Gy) increases by 10.4%, 9.7% and 9.4% for the IMRT, 3-field and 4-field plans respectively. **Conclusion:** Rectal DVHs for the IMRT plan seem to be more sensitive to patient-beam positioning uncertainties along the A-P direction in the medium dose region compared to the conformal plans. An acceptable plan, determined using dose constraints can become an unacceptable plan when geometric uncertainties are taken into account.

SU-FF-T-169

Dose Calculation Accuracy in the Presence of High-Z Materials Using Megavoltage CT for Treatment Planning

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Purpose: Verify the accuracy of the dose calculation algorithm in the presence of a hip prosthesis when planning with megavoltage CT (MVCT) images of the TomoTherapy Hi-Art II planning system. **Methods and Materials:** Artifacts from imaging high-Z materials are greatly reduced in MVCT compared to kilovoltage CT (kVCT). This may allow more accurate treatment planning for patients with metallic implants. The Radiological Physics Center's (RPC) pelvic phantom was modified to accommodate a commercial Co-Cr-Mo hip prosthesis and imaged with both kVCT and MVCT. On the TomoTherapy Hi-Art II planning system, the MVCT-to-density table was extended to high-Z materials by including stainless steel and lead in the calibration. Contours were drawn on kVCT images without the prosthesis present and fused to the MVCT image set. Helical tomotherapy plans were created using the MVCT images with no

constraints on beam entry or exit location. The delivered dose distribution was measured using TLDs in the PTV and EBT radiochromic film in the coronal and sagittal planes. Criteria based on TG-53 recommendations were used for comparison between measurements and calculations. **Results:** Dose calculation with MVCT images resulted in minor variations between calculated and measured dose. It was found that on average 97% of the dose distribution measured with film agreed with the treatment planning system to within +/-5% or 3mm. Profiles across the PTV also showed good agreement between measurement and calculation. The average TLD dose at the center of the PTV was 96.0% of the expected dose. **Conclusion:** Using dose calculations based on MVCT images, it is possible to accurately calculate the dose distribution in the pelvic region while treating through a high-Z prosthetic implant. Work was supported by PHS grant CA10953 and CA081647 awarded by NCI.

SU-FF-T-170

Dose Delivery to Curved Structures in Intra-Operative High Dose Rate (IOHDR) Brachytherapy

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Purpose: To investigate the magnitude of overdosage / underdosage for curved surfaces in intra-operative high dose rate (IOHDR) brachytherapy when the original treatment plan assumed a planar geometry. **Method and Materials:** The archived IOHDR brachytherapy treatment plans of 5 cases were used in this study. Plans of 3 patients treated in our facility were chosen for the different treatment surface areas and two plans with square fields were developed to compare with irregular shape of clinical cases. Phantoms with four various radii (5 cm to 13.5 cm) were used to simulate the treatment planning geometries which were calculated in 2-dimensional plans. EDR2 radiographic film dosimetry was used to evaluate the dose distribution for each case. Each film was digitized with 0.17 mm resolution using a film dosimetry system and converted to dose. **Results:** A 2-D planar implant was designed to deliver a dose of 200 cGy to the prescription depth. This implant applicator was then wrapped around curved phantoms of different radii and the identical treatment was delivered for each curved structure. However, the actual doses delivered to the prescription points were about 9 % (5.5 % for small treatment area - 3 catheter x 4 cm^2) higher for the convex with respect to the prescription point with 5 cm radius at 1 cm prescription distance. The actual delivered dose was increased linearly proportional to decreasing of the radius of convex. **Conclusion:** In IOHDR clinical cases, 2-dimensional planning geometry is typically used without considering the curved shape of the patient's structure. Our measurements have shown an overdosage when the original planar treatment plan was delivered in a convex setting resulting in an increase in the prescription depth which may be clinically relevant.

SU-FF-T-171

Dose Differences Due to Air Pockets in Mammosite Treatments for Partial Breast Irradiation

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Purpose: To evaluate the effect of air pockets on the delivered dose for MammoSite® treatments using Monte Carlo (MC) calculations, conventional treatment planning system (TPS), and TLD measurements. **Method and Materials:** A solid water phantom was designed and fabricated to simulate a MammoSite® treatment with an air pocket outside the balloon. Dose measurements were performed using TLD-100s with dimensions of 3 mm x 3 mm x 0.9 mm and sensitivity of $\pm$3%. The phantom was composed of twelve slabs of 30 cm x 30 cm Plastic Water with varying thicknesses to provide different measurement distances from the balloon surface. The balloon volume was 34 cc, with a diameter of 4 cm. No contrast medium was added to the balloon to avoid possible dose effects due to the contrast. Hemisphere-shaped air pockets with different radii were milled on top of the balloon surface. An MC algorithm with geometric modeling based on the phantom design was created for dose comparison. The dose discrepancies from the TPS, TLD measurements, and MC calculations were compared. **Results:** For a 25 mm air pocket, measured doses from TLDs at various locations of the customized phantom and MC results agreed with each other. The maximal discrepancy between TLDs and MC at different measured points was 3.68%. Dose differences between TPS and MC calculation at the air pocket was 6.37%, and less than 5% at locations other than air pockets. Doses will also be shown for a larger air pocket (5 mm radius). **Conclusion:** The air pocket located outside of MammoSite® balloon does affect the dose to surrounding tissue and this dose can be represented using MC calculations.

SU-FF-T-172

Dose Mapping for Interrupted Tomotherapy Treatments

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Purpose: To map out the dose delivered to a patient, when treatment is interrupted and not completed, several times while undergoing tomotherapy. **Method and Materials:** The patient data whose treatment had been interrupted 5 out of 25 fractions of 2 Gys was extracted. Two plans were used for patient treatment, plan 01 with field width of 1.06 cm and plan 02 with 2.49 cm field width. The data includes dose per fraction, total dose, total treatment time, t_t, duration of partial treatment, $t_{p;}$ field width, FW; couch speed and coordinates of the first CT slice with the target delineated. The treated distance from the first CT slice with target delineated is given by, Distance treated = ((t_p - 10.0s) x couch speed) – FW 10s is the time needed for machine warm up and the couch does not move during this time. A field width distance needs to be subtracted to account for the start of treatment when the proximal edge of the beam hits the superior most slice that contains the delineated target. Since 100 % of the prescribed dose is delivered in each treated slice, the prescribed dose per fraction can be subtracted from the untreated area, hence reducing the total dose in the untreated area for every untreated fraction. **Results:** The composite plan is then produced based on the subtraction of dose from various untreated sections. **Conclusion:** This method serves as a simple and fast way of approximating the composite dose to a patient with single or multiple interrupted treatment fractions, which are not completed. However, a more accurate computer based calculation that takes, into account the scatter dose, leakage dose and the partial delivery of the modulated beams may be needed to provide more accurate doses mainly at the junction of interruption.

SU-FF-T-173

Dose Per Monitor Unit Determination for Proton Therapy Treatment Portals with and Without the Range Compensator

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Purpose: To determine whether dose per monitor unit values (*D/MU*) for small-field proton therapy treatment portals can be more reliably measured with or without the field-specific range compensator present. Methods and Materials: Treatments of 14 geometric models representative of typical neurosurgery patients were simulated using a Monte Carlo model of the M. D. Anderson Proton Therapy Center-Houston double scattering nozzle. Simulations of field-specific *D/MU* calibration measurements were carried out in a water phantom with and without the range compensator present. *D/MU* values from each calibration technique were compared to values from the patient treatment simulation. For each case, *D/MU* values were scored with metrics that characterized the accuracy, uncertainty, the standard deviation of accuracy and uncertainty, worst agreement, and maximum uncertainty. The metrics were combined by defining the following figures of merit (FOM), which ranged in value from 0 to 1 (0 being worst, 1 being best): total FOM (a composite of all metrics), clinical FOM (accuracy and uncertainty metrics), variability FOM (standard deviations of accuracy and uncertainty metrics), and worst-case FOM (worst agreement and maximum uncertainty metrics). The two *D/MU* calibration techniques were compared based on the FOMs. **Results:** the total fom when measuring without the range compensator was 0.85 and 0.49 with the compensator. The clinical, variability, and worst-case foms were 0.85, 0.92, and 0.79, respectively, without the range compensator, compared to 0.51 (clinical), 0.48 (variability), and 0.46 (worst-case) with the range compensator. The superiority of calibrating without the compensator was mainly attributable to the fact that the dose distributions were more similar to those in the patients. Additionally, determining *d/mu* values without the compensator is conceptually simpler and more convenient. **Conclusion:** For the 14 cases considered in this work,

measuring *D/MU* without the range compensator provided more reliable values of *D/MU* than measuring with the range compensator.

SU-FF-T-174

Dose Rate Dependence of Film Dosimetry in Radiation Treatment: Study of Reciprocity Law

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Purpose: Film has become an important tool for dose verification in individualized IMRT treatment fields. The optical density (OD) is related to dose rate also known as reciprocity law; (D= Dr*t). However for modern films (EDR and XV) reciprocity law has not been investigated which is presented in this study. **Method and Materials:** Using a Varian linear accelerator, dose rate dependence was studied for Kodak films (XV and EDR). The dose rate on this unit could be varied in the range of 80-400 MU/min for both (6 MV and 15 MV) photons beams. A large dose rate range; 5 cGy/min –1100 cGy/min was achieved in conjunction with distance (1-4 meters) and machine dose rate. This was verified using ion chamber. At each dose rate, films were exposed in a solid phantom at a depth of dmax for 300 cGy and 50 cGy for EDR and XV films, respectively. Calibration curves (dose vs. OD) were also established during this experiment in a standard condition. The measured dose through film and ion chamber were compared and analyzed. **Results:** Reciprocity law holds good in the dose rate range of 20-400 cGy/min for both energies but deviates at low and high dose rates. The effect is more pronounced at dose rate beyond 400 cGy/min where deviation up to 7.5% was noted for both the films. At low dose rate, the deviation is –3.5% for both films and energies. **Conclusion:** Low and high dose regions are created in the same time of exposure in IMRT and hence reciprocity law becomes critical for film dosimetry. The reciprocity law failure is due to the interaction of ion pairs to form latent image, which could be suppressed at extreme dose rates. The dosimetric impact is noted to be up to 7.5% for both films.

SU-FF-T-175

Dose Rate Optimization for Intensity-Modulated Arc Therapy

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Purpose: We use multiple dynamic arcs with different MLC shapes at different gantry angles for Intensity-modulated arc therapy (IMAT). This study is to develop a fast and simple algorithm to optimize the dose rate as a function of gantry angle for IMAT for linear accelerators with dose rate variation capability for a dynamic arc. **Method and Materials:** The dose rate as a function of gantry angle for a dynamic arc is expressed by an analytical expression that favors beam directions with lower dose deposited to critical structures and higher dose deposited to the target volume. Three parameters are included in the analytical expression for further optimization of the dose rate base on an objective function. The optimized plan is transferred to a forward treatment planning system for final dose calculation. The method is applied to a phantom and a few clinical cases using 6 MV and 18 MV beams for a Varian linear accelerator. **Results:** The method has been demonstrated with a test phantom and a few clinical radiotherapy cases. We have showed that dose distributions and dose volume histograms have been improved with the dose rate optimization for IMAT. It gives more uniform dose to the target volume and lower dose to the critical structure. **Conclusions:** We have developed a fast and simple technique to optimize the dose rate as a function of gantry angle for intensity-modulated arc therapy, while retaining its advantages of an intuitive treatment planning process and efficient radiation delivery.

SU-FF-T-176

Dose Verification in Moving Targets During Helical Tomotherapy Beam Delivery

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Purpose: To compare dose distributions from stationary and moving targets subject to simulated intra-fraction motion during treatment deliveries on a helical tomotherapy unit. **Method and Materials:** We have constructed an in house platform that moves in the superior-inferior direction in a controlled manner. Using a stationary CT scan of a thorax phantom, a fictitious target volume was defined and a helical tomotherapy plan was generated. The phantom was placed on top of the moving platform and set in motion at a frequency of 16.7 cycles/min and 20 mm peak-to-trough excursion. An IMRT plan was delivered while the phantom was in motion and when it was still. Ion chamber readings were recorded at the center of the target. Different phases were artificially introduced by starting the platform motion at different times before the start of irradiation. In each delivery a film was placed in the coronal plane inside the phantom to register 2D dose. **Results:** Profiles along the direction of motion from the co-registered images of moving and stationary deliveries have shown dose differences as large as 70% in the penumbra region. Gamma function maps for different dose and distance to agreement criteria revealed the regions at which the gamma criteria fails and was shown to be a strong function of initial motion phase. Ion chamber point measurements recorded insignificant differences between still and moving deliveries. **Conclusions:** We have shown that there is a significant difference in 2D dose distributions in the penumbra region both in the inferior-superior and transverse directions between stationary and moving deliveries that simulate breathing motion. Our results indicate that the differences are highly dependent on the breathing motion initial phase. The phantom motion had little effect on the delivered dose at the central target region.

SU-FF-T-177

Dose-Volume Histogram Objectives in Multi-Criteria IMRT Optimization

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Purpose: Dose-volume histogram (DVH) constraints are frequently used in IMRT planning. For example, a DVH constraint may state that 5% (but no more) of the voxels in the planning target volume may receive a dose below the prescription level. We want to find out if the percentage of violating voxels can be reduced. We are also interested in the "price" of this reduction of violating voxels, in terms of dose to other voxels and other structures. Methods and Materials: We introduce DVH objectives into IMRT planning. Here the objective is to minimize the number of voxels that violate a given dose constraint. We then integrate DVH objectives into a multi-criteria optimization (MCO) framework, to analyze the trade offs between DVH objectives and other planning objectives. Relaxation of mixed integer programs (MIPs) used to produce the trade off curve yields a good approximation. This is contrary to relaxation of an MIP with DVH constraints in the conventional framework. A heuristic then fine tunes the relaxation results. **Results:** Our methods are applied to two clinical cases with both a dose-volume objective on the tumor and a maximum dose objective on OAR. The trade off curve between those two objectives is calculated in around 20 minutes with the relaxed MIPs compared to 40 hours with the nominal MIPs. The two techniques differ on average by only .77% tumor volume coverage and the heuristic reduces this difference to .35%. **Conclusion:** The use of DVH objectives (instead of DVH constraints) has the potential to lead to better trade offs in IMRT treatment planning. Surprisingly, DVH objectives simplify the numerical handling of the problem and reduce calculation times.

SU-FF-T-178

Dosimetric and Technical Aspects of Intraoperative I-125 Brachytherapy for Stage I Non-Small Cell Lung Cancer

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Purpose: Initial outcome data from our institution have shown that sublobar resection in combination with I-125 brachtherapy is associated with recurrence rates of 2.0%, compared to 18.6% with sublobar resection alone. The objective of this work is to present the technical and dosimetric aspects required to execute this procedure from the radiation oncology perspective, as well as to analyze the dose distributions of patients treated with this technique. **Method and Materials:** I-125 seeds in vicryl suture were embedded into vicryl mesh and surgically inserted providing a 2.0 cm margin on each side of the resection staple line. A nomogram was developed to determine the suture spacing in the vicryl mesh, as a function of seed activity in order to deliver 120 Gy at a distance of 0.5 cm above and below the seed array. Postoperative dosimetry consists of CT-based planning and dose volume analysis. **Results:** Dose distributions, DVH

data, mean dose and NTCP values for lung were analyzed in a group of patients. The mean doses ranged from 3.72 Gy to 9.10 Gy. NTCP values were below 1%. DVH data shows that a small volume of ipsilateral lung was irradiated for all patients. A comparison of brachytherapy with external beam therapy was investigated for one patient. Brachtherapy was judged to be superior to external beam therapy. Results showed that most of the ipsilateral lung volume received a lower dose when treated with an implant to 120 Gy compared to external beam therapy treated to 60 Gy. **Conclusions:** Lung brachytherapy with I-125 at the time of sublobar resection is a precise and conformal option of dose delivery for stage I NSCLC patients with compromised physiologic reserve. Patient related toxicity has not been linked to this procedure. This simple technique provides significant lung sparing when compared to standard external beam therapy.

SU-FF-T-179

Dosimetric Characteristics of a Titanium Clad 90Y Plaque for Irradiation of Sarcomas of the Spine

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Purpose: A ^{90}Y foil encased in polycarbonate plaque has been used to irradiate the dura for sarcomas of the spine. The plaque is applied to the dura intraoperatively after radiation therapy and surgery. Rapid falloff of % DD allows the surface of the dura to be treated and the spinal cord a few millimeters below to be spared. Fabrication of a polycarbonate plaque is a difficult process. Radiation and heat damage from the nuclear reactor used to activate the foil will compromise the polycarbonate housing. Requiring the plaque to be assembled in a glove box after the foil has been activated. This process limits design parameters. A new plaque design incorporating a ^{90}Y foil encapsulated in titanium has been developed to facilitate the manufacturing process. The plaque may be assembled before activation allowing for more flexibility in design. **Method and Materials:** To study the dosimetric characteristics of this new plaque design, a flat plaque was constructed for measurements with radiochromic film. Surface profiles and %DD were measured and compared to previous results for a polycarbonate encapsulated ^{90}Y foil and to MCNP calculations generated for the new plaque. Surface profiles were evaluated using a Therapeutic Width Index (TWI), defined as the width of the surface profile at 90% divided by the width of the ^{90}Y foil. **Results:** The titanium plaque's %DD measurements agreed well with the MCNP calculations and with the polycarbonate plaque measurements. Surface profiles for the titanium plaque were measured and the average TWI was 0.88. The average TWI for the polycarbonate plaque was 0.77. The increase in TWI for the titanium plaque corresponds to a 30% increase in useful treatment area. **Conclusion:** Similar %DD characteristics and an increase in useful treatment area show the new plaque design to be clinically acceptable.

SU-FF-T-180

Dosimetric Characteristics of Tm-170 as a Radionuclide for Its Possible Use in Brachytherapy

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In clinical brachytherapy several types of photon sources are used, mainly Cs-137, Ir-192, I-125, and Pd-103. The Tm-170 is a promising radionuclide for use in brachytherapy because of the low mean-energy (46.75 keV or 66.39 keV if the lines below 10 keV are removed) and the possible high specific activity (2.21×1014 Bq/g for a half life of 128.6 days). Tm-170 is produced in a nuclear reactor by neutron absorption of the natural Tm-169 and decays mainly via β-emission. The maximum energies of the β-rays are 0.290 and 0.323 MeV. These β particles are thus absorbed in the source core and in the encapsulation cover producing bremsstrahlung that contributes significantly to the dose. These facts must be taken into account to design Tm-170 sources in order to calculate source and encapsulation thicknesses. The purpose of this study is to determine by means of the Monte Carlo method the dosimetric characteristics for a Tm-170 point source and for a hypothetical spherical source with an active core of Tm-170 encapsulated by a titanium or stainless-steel cover. Different active radius and cover thicknesses have been considered. The Monte Carlo GEANT4 code was used in this study to obtain the radial dose function of the sources studied. The radial dose function obtained is similar to the radial dose function of Ir-192 or Cs-137 sources. This fact and the low energy of the photons emitted by Tm-170 makes this radionuclide very interesting for its use in HDR or PDR brachytherapy. This study may be interesting for manufacturing future Tm-170 sources.

SU-FF-T-181

Dosimetric Comparison of a Semi-Conductor Array (MapCheck), EDR2 Film and Ion-Chamber in the Commissioning of Enhanced Dynamic Wedges On a Varian Linear Accelerator (21 EX)

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Purpose: To evaluate the accuracy of Mapcheck, EDR2 film and ion-chamber for enhanced dynamic wedge (EDWs) on a Varian Linear Accelerator (21-EX). **Method and Materials:** Dosimetric measurements for the entire range of available field-sizes (4x4cm^2 to 30x30cm^2) for both 6- and 23-MV photon beams on 21-EX were performed as a part of commissioning of EDWs. Eclipse computed dose profiles in the coronal plane at 5cm depth for 100MUs were compared with measurement using a 445 diode-array (MapCheck; Sun Nuclear Corp.) after calibrating it for relative and absolute dosimetry. Planar dose measurements were also repeated using EDR2 radiographic film. Each film was digitized with 0.17mm resolution using the RIT 113 film dosimetry system (Radiological Imaging Technology) and converted to dose using an appropriate H&D curve. These measurements were also compared with those made using a 0.6cc Farmer chamber. **Results:** For the majority of the EDWs and field size geometries, the CAX dose values between MapCheck measurement and Eclipse computed values were within 2% except for very large wedge angles at large field sizes. Interestingly, for field sizes less than 10x10cm^2, the results of MapCheck device demonstrated a better agreement to the TPS computed values than those of ion-chamber measurement which could be attributed to the miniature size of the diode detector. Also, EDR2 film dosimetry showed consistent 2-3% over-response for all wedge angles and field sizes which was very evident at the toe region of EDW. **Conclusion:** The three measurement detection systems were used to verify the beam profiles and depth doses of EDW. Our results have demonstrated the superiority of MapCheck device in the commissioning and routine QA of EDW over EDR2 film that had an inherent over-response of 2-3% despite an appropriate H&D curve. The only disadvantage of the Mapcheck device was its restrictive measurement area of 20x20cm^2.

SU-FF-T-182

Dosimetric Comparison of An Elekta "Synergy S" Beam Modulator & Radionics MMLC Using Monte Carlo Simulations & Measurements

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Purpose: To compare dosimetric parameters of a new Elekta "Synergy S" dedicated stereotactic radiosurgery MLC, namely the beam modulator (BM), with Radionics mini-multileaf collimator (MMLC). **Methods and Materials:** The Beam Modulator maximum opening is 16cmx21cm and consists of 40 pairs of Tungsten leaves of 4mm thickness at the isocentre, with no back up jaws. Radionics MMLC has a maximum field size of 9.6cmx12cm and 3.75mm leaf thickness at the isocentre. Leakage and transmission, percentage depth doses (PDD) and dose profiles were measured and calculated for different field sizes and depths and for different source to surface distances (SSD). Kodak XV films, photon diode detector (diameter of active area 2mm), CC13 Wellhofer ion chamber (cavity volume 0.13 cm3) and Wellhofer water tank were used for measurements. BEAMnrc code was used for the Monte Carlo (MC) simulations. All the data are for a 6MV photon beam. **Results:** It is shown that the BM beams are slightly more energetic so that PDD at 10cm depth is 2% more for a 10.4cm x 9.6cm field, compared to Radionics MMLC. Dose profile results are generally comparable, except for the penumbra which is sharper for Radionics MMLC, especially in the leaf travel direction by up to 1.1 mm. Maximum and average leakage was 1.7 and 1.1 for BM and 1.2 and 0.9% for MMLC, respectively. MC calculation and measurement results for PDD and profiles agreed well to better than 1% and or 0.5mm. The uncertainty in simulation was less than 0.5%. **Conclusion:** Elekta "Synergy S" beam modulator and Radionics MMLC have successfully been modeled for the first time using the BEAMnrc MC

simulations. The MC results showed an excellent agreement with the measurements. BM has a wider penumbra, mainly due to the larger isocentric distance and rounded leaf ends.

SU-FF-T-183

Dosimetric Comparison Of Gamma Knife Vs. CyberKnife Radiosurgery For Patients With Tumors Near Optic Apparatus

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Purpose: We reviewed our 10-year experience with GK radiosurgery (GKRS) and recent experience with CK radiosurgery (CKRS) for patients with tumors near optic apparatus to make a dosimetric comparison between the two modalities. **Method and Materials:** From 1994 to 2004, a total of 186 patients (165 GKRS and 21 CKRS) with tumors near the optic apparatus were treated. The majority of this group included 80 meningiomas and 93 pituitary adenomas. Dosimetric parameters, such as, the conformity index, tumor coverage, the closest distances and the maximum radiation doses to optic apparatus and brainstem were evaluated between the two modalities. **Results:** Mean tumor volume was 4.5cm^3 (0.2 to 20.7cm^3) for GKRS and 11.0cm^3 (0.9 to 38.7cm^3) for CKRS. The maximum doses to optic apparatus and brainstem were significantly higher ($p < 0.05$) even though the closest distances to the structures were very similar. For a subgroup of GKRS patients (n=40) with a mean of tumor volume equivalent to that of CKRS, radiation dose to brainstem was virtually comparable. The mean conformity index was1.35 for CKRS, 1.68 for all GKRS patients (n=165) and 1.49 for the subgroup of GKRS (n=40) in favor of CKRS. The mean tumor coverage was 98.4% for CKRS, 96.0% for all GKRS patients, and 90.9% for the subgroup in favor of CKRS also. **Conclusion:** CKRS provides excellent radiation conformity and tumor coverage by means of the non-isocentric beam delivery. However, due to the limits of beam access, the dose fall-off for CKRS is less rapid, resulting in higher radiation doses to the critical structures. GKRS is best used for small tumors located at least 2mm from the visual pathways. CKRS can be used but is not limited to tumors abutting the optic apparatus or for tumors greater than 3 millimeters in size. This is accomplished via dose fractionation.

SU-FF-T-184

Dosimetric Comparison of LDR, HDR, and IMRT for the Treatment of Advanced Stage Cervical Cancer

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Purpose: While perineal template-based LDR Brachytherapy has been the treatment of choice for advanced stage cervical cancers, recently, there is increasing interest in HDR and IMRT treatments for this disease. This study compares LDR, HDR and IMRT dose distributions, using biological effective doses (BED's), based on a Linear-Quadratic model.[1] Methods and Materials: Afterloading needles were implanted in the OR using Syed-Neblett templates. A physician outlined the target, the rectum, and the bladder volumes on CT-MRI fused images. Images and structures were transferred to Pinnacle-III, Plato, and Corvus planning systems, used for LDR, HDR, and IMRT, respectively. Dosimetry parameters for the target (D100, D90, D50, D10) and for rectum and bladder (D50, D30, D20, D10), were transformed to BED's for comparison. **Results:** Three patients were analyzed in this study. Plans were created for the same BED doses in these three modalities. Dosimetry parameters were normalized to D90. Average D100 values in LDR, HDR, and IMRT were 56%, 55% and 87% of D90, respectively. Although dose coverage in the target region was comparable in LDR and HDR, average value of D10 was higher in HDR than LDR (by 25%). However, average D30 and D50 values were comparable in LDR and HDR. In IMRT, average D10 was only about 8% higher than D90, indicating superior dose homogeneity. Rectum and bladder doses were lower in IMRT and in HDR compared to LDR. **Conclusion:** While dose inhomogeneity in the target region was higher in HDR than LDR, normal structure doses were lower. IMRT provided better dose homogeneity and target coverage, and delivered lower doses to normal structures than LDR. Therefore, HDR and IMRT seem to be better for the treatment of advanced stage cervical cancer. IMRT has the added advantage of being non-invasive. (1)C. C. Ling, et. al. Radiotherapy and Oncology, 25 (1992) 103-110.

SU-FF-T-185

Dosimetric Comparison of Tandem and Ovoids Vs. Tandem and Ring for Intracavitary Gynaecologic Applications

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Purpose: To evaluate dosimetric differences in Tandem and Ovoid (TO) and Tandem and Ring (TR) gynaecologic brachytherapy applicators. **Method and Materials:** 10 patients with cervical cancer (stages II-IV) were treated with three brachytherapy applications: either one TO and two TR, or one TR and two TO applications. All patients underwent CT scans at 2.5 mm slice thickness. Contrast was inserted into the bladder prior to scan. Patients were prescribed 8 Gy to ICRU points A, with additional optimization goals of maintaining the traditional pear-shaped dose distribution and limiting bladder and rectum doses to below 6 Gy. ICRU bladder and rectum point doses, as well as mean and maximum doses were calculated. Maximum dose was defined as the highest dose received by 2cc of the organ. Total treatment time and volumes treated to 95%, 85% and 50% of the prescription dose were also compared. Data were analyzed using the Mann-Whitney rank-sum test. **Results:** There were no significant differences between TO and TR applicators in doses to prescription points or to critical organs. However, there was a significant difference ($p<0.05$) between the applicators in the treated volumes and total treatment time. The TO treated larger volumes over a longer time. The treated volumes were also found to be significantly different between applicators within each patient ($p<0.05$, Chi-square). **Conclusion:** Our results demonstrate that the two applicators, whilst delivering prescription doses to points A and keeping critical organ doses within tolerance, treat significantly different volumes. It is unclear if this difference is clinically advantageous or not. TO applicators may be treating healthy tissue unnecessarily, or TR applicators may be underdosing tumor tissue. Further investigation with appropriate imaging modalities is required for accurate delineation of target volumes. Clearly, the TR and TO are *not* identical, and should not be used interchangeably without further study.

SU-FF-T-186

Dosimetric Effect of Patient Rotational Setup Errors On Prostate IMRT Plans

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Purpose: To determine dose delivery errors that could result from systematic and random rotational setup errors for prostate patients treated with IMRT. Methods and Materials: Five prostate cancer patients treated with IMRT technique had their dose distributions re-evaluated to assess the impact of systematic and random rotational setup errors. The IMRT treatments were delivered in three phases: 54 Gy to 95% of PTV1 (prostate and seminal vesicle plus a 10mm margin), 16.2 Gy to 95% of PTV2 (prostate plus a 5mm margin), and 5.4Gy to 95% of PTV3 (which was PTV2 excluding rectum). Rotational setup error can be equivalently simulated with matrix transformed equations by using the gantry, collimator and couch angles of treatment beams. Systematic rotational setup error $\Delta\Phi$ was simulated around each of the three Cartesian axes (denoted as $\Delta\Phi_{LR}$, $\Delta\Phi_{AP}$, $\Delta\Phi_{SI}$) respectively. The dosimetric effect of random rotational setup error ($\Delta\sigma$) was also simulated with normal probability distribution. Various dosimetric parameters for the targets and surrounding normal organs were evaluated with respect to the IMRT plan used for treatment. **Results:** The cumulative dosimetric deviations of target (prostate) were within 1% when $\Delta\Phi$ and $\Delta\sigma$ were up to $\pm5^o$ and 3^o respectively. For OARs, when $\Delta\Phi_{LR}=\Delta\Phi_{AP}=\Delta\Phi_{SI}=5^o$ was simulated, the V_{40Gy} and V_{70Gy} of rectum deviated by 5.8±3.6% and 6.1±11.8% respectively, the V_{40Gy} and V_{65Gy} of bladder deviated by –1.0±2.9% and –1.9±4.4%. When $\Delta\sigma_{LR}=\Delta\sigma_{AP}=\Delta\sigma_{SI}=3^o$ was simulated, the V_{40Gy} and V_{70Gy} of rectum deviated by –0.4±0.4% and –2.9±3.2%, the V_{40Gy} and V_{65Gy} of bladder deviated by 1.6±1.5% and 0.6±1.5%. **Conclusions:** For three phases sequential boost prostate IMRT technique, the rotational setup errors do not have a significant dosimetric impact on the cumulative target coverage when $\Delta\Phi$ and $\Delta\sigma$ were up to $\pm5^o$ and 3^o respectively. However, reduction of rotational setup errors can decrease doses to surrounding normal structures.

SU-FF-T-187

Dosimetric Evaluation of MammoSite Breast Treatments

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Purpose: This study was performed to assess the volumetric dosimetry of single point optimization with single dwell position technique for MammoSite brachytherapy treatment and compare the results with accepted dosimetric constraints in the ongoing NSABP B39/RTOG 0413 partial breast irradiation protocol. **Method and Materials:** 74 patients received MammoSite breast treatments with single dwell position, single point optimization technique using orthogonal film based planning. CT-images were transferred to the PLATO treatment planning system version 14.2.6 and retrospectively planned for volumetric calculations without changing dwell time and position. The D90, V100, V150 and V200 and dose homogeneity index (DHI) were calculated. For comparison 9 randomly selected patients were planned with 3D volumetric optimization using multiple dwell positions and compared with 2D plan. **Results:** The mean D90 and V100 were 96% and 88% respectively. The mean V150 and V200 were 26 cc and 3.4 cc. The mean DHI was .68. All except three patients met the dosimetric criteria and constraint required in protocols. Two patients had D90 of 88.5% and 89% instead of ≥90% and another patient had V200 of 18cc instead of ≤10cc. The D90 and V100 for single vs. multiple dwell position were 93% vs. 98% (p= .0003) and 86% vs. 97% (.0004) respectively. The V150 and V200 were 23.5 cc vs. 34 cc (p=.0006) and 2.9 cc vs., 7.2 cc (p< .0001) respectively. The DHI was .71 vs. .61 (p=.0006). **Conclusion:** Single dwell position with single point optimization gives acceptable coverage and meets the requirements outlined in the NSABP B39/RTOG 0413 protocol in majority of patients. The multiple dwell position technique can generate plans with significantly better dose coverage of target but at the cost of increased dose inhomogeneity and increased hot spot. Correlations of outcomes with dosimtery will better help us assess these different treatment plans.

SU-FF-T-188

Dosimetric Evaluation of Parallel Opposed GRID Radiation Therapy for Deep-Seated Bulky Tumors

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Purpose: Grid radiation therapy, using single field of megavoltage x-ray beam has been proven to be an effective method for management of bulky (>8 cm in diameter) malignant tumors. However, the effectiveness of this treatment modality for deep seated tumor is limited by the dose to the overlying normal tissue. In this investigation the use of parallel opposed beam is being evaluated for treatment of deep seated bulky tumors, using two different grid patterns. **Method and Materials:** Dosimetric characteristics of single field and parallel opposed radiation field were experimentally determined with film in Solid Water phantom material and using ion chamber in water. These measurements were performed with 6 and 18 MV x-ray beams from a Varian Clinac 2100EX linear accelerator. Two different Grid block patterns, fabricated by Radiation Products Design, Inc. were utilized in these investigations. The GRID blocks molded into a cerrobend block of 7.5 cm thickness were manufactured with hole diameters of 5.9 mm and 8.5 mm. **Results:** Dose profiles and percentage depth doses of two GRID blocks for the parallel opposed beam were compared with a single radiation field. The results of these investigations indicated that with a 5.9 mm GRID block, dose to the overlaying normal tissue at d_{max} reduced from 200% for a single field to 100%, for the same tumor dose, with equally weighted parallel opposed fields. Similarly, for the 8.5 mm GRID block, dose to normal tissue at dmax were reduced from 185% to 100%. **Conclusion:** Parallel opposed GRID therapy resulted in a substantial decrease in dose delivered to the normal tissues for the same prescribed tumor dose. Thus, parallel opposed GRID radiotherapy is a viable option for treatment of deep-seated bulky tumor. With this technique, the tumor dose can be increased for a higher therapeutic result.

SU-FF-T-189

Dosimetric Figures-Of-Merit Based Comparison of Three IMRT Modalities: Helical Tomotherapy, Sequential Tomotherapy and DMLC-IMRT

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Purpose: Intensity modulated radiation therapy (IMRT) can be delivered using several different techniques. The present study compares dosimetric characteristics of three commercial IMRT planning and delivery systems, i.e., helical tomotherapy (TOMO), sequential tomotherapy with MIMiC (MIMiC) and dynamic multileaf collimated IMRT (DMLC-IMRT). **Method and Materials:** IMRT plans for three common clinical cases, head-and-neck (HN), brain and prostate cancers, were generated using respective RTOG protocols 9406, 9803 and H0022 as guidelines. For each case, multiple (more than four) plans were produced for each technique using different strategies by adjusting constraints and/or parameters such as beam width, modulation factor, the number of fields, etc. Dosimetric indices were used as figures-of-merit to evaluate the plans. These indices include coverage index (CI), overflow index (OI), sparing index (SI), and overall conformal index (COIN), where COIN=CI×OI×SI. The plans for each technique were compared among themselves to determine the best plan of each technique which in turn was used for the comparison of different techniques. **Results:** For the HN case, the COINs for TOMO, MIMiC and DMLC-IMRT were 0.333, 0.064 and 0.305, respectively. TOMO had highest SI, but DMLC-IMRT had highest CI and OI. MIMiC plan performance was poorer than TOMO and DMLC-IMRT for the HN case. The COINs for TOMO, MIMiC and DMLC-IMRT were 0.471, 0.616 and 0.685 for the brain case, and 0.304, 0.487 and 0.554 for the prostate case, respectively. DMLC-IMRT had the highest COIN for both the brain and prostate cases. TOMO had best coverage for the brain case while DMLC-IMRT had best coverage for the prostate case. **Conclusion:** IMRT plan optimization is a process to balance and compromise between target coverage and normal tissue sparing. The three techniques may result in different plans for similar constraints. Using different strategies, all three techniques produced clinically acceptable treatment plans for all cases.

SU-FF-T-190

Dosimetric Impacts of Smaller Pencil Beam Utilizing in Smaller Intracranial Lesions On Intensity Modulation Serial Tomotherapy

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Purpose: To test the dosimetric feasibility of using a smaller size circular pencil beam on small intracranial lesions in serial tomotherapy based radiosurgery. **Method and Materials:** An in-house post collimation device (Gizz) was developed to refine the NOMOS Peacock pencil beams to an array of 5 mm diameter circular pencil beams. Beam characteristics were investigated and implemented into the treatment planning system. Eighteen patients with small irregular intracranial lesions (0.19 to 3.21c.c, mean 1.21c.c) were selected in groups of arteriovenous malformation (n = 6), acoustic neuroma (n = 6), and metastatic lesion (n = 6). Plans were calculated with the refined smaller size circular pencil beam and a 4 mm x 10 mm rectangular pencil beam in Corvus 6.0. A novel strategy of normalizing plans to 97% target volume covered by 100% prescription line was adopted. Plan quality was characterized, for the purposes of the study, by conformity and homogeneity indices, mean, maximum and minimum does to target and critical structures, and volume of healthy tissue receiving various dose levels. **Results:** This new pencil beam provided a better two-dimensional resolution than three available commercial rectangular pencil beams. Due to adjacent gap spaces from this new physical design, a new couch indexing approach was proposed. Clinical selected cases experienced an average 15% conformity improvement utilizing this smaller pencil beam associated with better normal tissue avoidance. Results reflected that the performance of this device is dependent on target coverage, target volume, and beam displacement location. **Conclusion:** Smaller pencil beam is an option to improve the target comformality for small irregular lesions in serial tomotherapy based radiosurgery. Future works on optimized pencil beam size, shape, isocenter shift should be accomplished.

SU-FF-T-191

Dosimetric Improvement in Treatment of Advanced-Stage Nasopharyngeal Carcinoma Using Split Organ Delineation Approach and Multiple Virtual Organs Generation Approach in Intensity-Modulated Radiation Therapy Dose Optimization

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Purpose: To evaluate the efficacy of improving target coverage and sparing of the organs-at-risk (OARs) using split organ delineation approach (SODA) and multiple virtual organs generation approach (MVOGA) in planning of intensity-modulated radiation therapy (IMRT) for advanced-stage nasopharyngeal carcinoma (NPC) **Method and Materials:** Twenty NPC patients with T3-4 tumors were selected. For each patient, a reference (REF) IMRT plan was generated with optimized target coverage and sparing of OARs. An investigative plan (INV) was also generated with the same planning protocol as the REF plan, with the exceptions that first, the contours of the parotid glands and temporal lobes were split into target-overlapping and non-overlapping regions, and second, multiple virtual organs were created to represent the normal tissues (such as segments of mucosa and muscles that are not conventionally designated as OARs). Each of the split and virtual organs was assigned with independent dose-volume constraints. The REF and INV plans were compared with respect to the conformity index (CI), and dose-endpoints of the OARs using paired-t test. **Results:** The INV plan was superior to the REF plans in terms of the CI of the GTVs (0.55 vs 0.50, p = 0.017), CI of the PTVs (0.79 vs 0.70, p =0.000), and the minimum dose of the PTVs (47.2Gy vs 44.8Gy, p=0.008). For the OARs, there was significant reduction in dose in the INV plan in terms of the mean dose (max 4.6Gy, p=0.003) to the parotid glands, the maximum dose (max 10Gy, p<0.024) and the mean dose (max 6Gy, p<0.000) to the virtual organs. **Conclusion:** Using a split organ delineation approach and multiple virtual organs generation approach in IMRT treatment planning, further dosimetric improvement in target coverage in the regions that overlapped with organs-at-risk can be achieved, together with sparing of the parotid glands and normal surrounding tissues.

SU-FF-T-193

Dosimetric Study and In-Vivo Dose Verification for Conformal Avoidance Helical Tomotherapy of Anal Adenocarcinoma

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Purpose: Recent studies have shown that for patients with anal canal malignancies, conformal avoidance intensity-modulated radiotherapy (IMRT) could provide better dose homogeneity and sparing of organs-at-risk (OARs) than conventional 3-D radiotherapy techniques. As a new IMRT technique, helical tomotherapy could achieve better dose modulation, and was expected to deliver adequate dose to surface lesion using tangential beams. This study aims to have dosimetric comparison between conformal avoidance helical tomoterapy plans and step-and-shoot IMRT plans for patients of anal adenocarcinoma, and to test the efficacy of helical tomotherapy for skin dose delivery. **Method and Materials:** We retrospectively generated conformal avoidance step-and-shoot IMRT (sIMRT) plans and helical tomotherapy plans for two anal cancer patients, one male and one female, with PTV volume being 5,622 cm^3 and 5,280 cm^3, respectively. The CORVUS Treatment Planning System was used to generate 7-field sIMRT plans. Helical tomotherapy plans used a jaw width of 2.5 cm. In-vivo skin dose measurements were performed using diodes placed on surface lesion and skin of external genitalia during conformal avoidance helical tomotherapy treatments of a recent anal cancer patient. **Results:** Compared to the sIMRT plans, the helical tomotherapy plans showed significant improvement of dose homogeneity for the PTVs, sharper dose drop-off outside the PTVs, and significantly less radiation to femoral heads and external genitalia in terms of maximum dose and average dose. In-vivo dose measurements showed adequate dose delivery to the surface lesion, and verified reduction of radiation to the skin of external genitalia. The maximum deviation of diode measurement from plan dose is 5.5%. **Conclusion:** Helical tomotherapy plans showed better dose homogeneity and conformity to the PTV and better sparing of OARs in conformal avoidance treatments of anal cancer compared to sIMRT plans. In-vivo dose measurements confirmed the ability of helical tomotherapy for adequate skin irradiation.

SU-FF-T-194

Dosimetric Validation of Tomotherapy in Hetergeneous Media

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Purpose: Helical Tomotherapy is a relatively new treatment modality that is being used to treat lesions that lie within and near low-density organs. Accurate dose calculations are critical to the effective use of this modality. This study quantified the Tomotherapy treatment planning system (TPS) convolution-superposition-based dose calculation accuracy in heterogeneous media. **Method and Materials:** This evaluation required a custom fabricated dosimetry phantom with lung-equivalent and water-equivalent media. The phantom consisted of an 18X18X18 cm^3 cuboid constructed from slabs of water-equivalent and lung-equivalent materials (LN300 Gammex RMI, Middleton, WI (ρ ~0.3g/cc), and Balsa wood (ρ ~0.1g/cc) and imaged on a CT scanner. Dose measurements were conducted using both film and ionization chambers using the same phantom geometry. Evaluations were conducted using an esophageal treatment plan, delivering 1.8 Gy/fraction, was superimposed onto the phantom CT-datasets and computed the dose distributions using the Tomotherapy treatment planning system. Radiochromic film (EBT, International specialty Products, Wayne, NJ) sheets were inserted between slabs of virtual water and lung equivalent material LN-300. Experiments were repeated with radiographic film (Kodak EDR2, Eastman Kodak, Rochester, NY) with balsa wood. Calibration curves for absolute dosimetry for both types of film were generated from additional film exposures and ion chamber measurements on the Tomotherapy unit. Ionization-chamber measurements were performed to confirm the film dosimetry. **Results:** Doses measured inside the water-equivalent plastic were within 2% of the computed doses by the Tomotherapy planning system. Measurements with radiochromic film in LN-300 material verified that the planning system computed the doses within 5%. Similar results were observed with EDR2 film in Balsa wood. **Conclusions:** The dose calculation accuracy of TPS was measured to be within 5% in lung material and within 2% in water-equivalent plastic. This work supported in part by Tomotherapy, Inc.

SU-FF-T-195

Dosimetry Audit for Tomotherapy Using Alanine/EPR

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Purpose: To provide an audit of ion chamber-based dosimetry for IMRT delivered by helical tomotherapy. **Method and Materials:** Three treatment plans were selected from the commissioning of a TomoTherapy Hi-Art II machine using a 30 cm diameter cylindrical Virtual Water ("cheese") phantom. For each plan, measurements were made at 6 points: two in the target volume, two in the steep dose-gradient region just outside the target volume, and two in the low-dose region far from the target volume, which was a 6 cm diameter cylinder. Absorbed dose was measured using two independent alanine/EPR dosimetry systems and two Exradin A1SL ion chambers. The planned dose in the target volume was 2 Gy per fraction, and 9 or 10 fractions were delivered to the phantom loaded with alanine dosimeters. The ion chambers had been calibrated in a ^{60}Co beam at Ghent University Dosimetry Laboratory, and correction factors were applied for beam quality and ion recombination as recommended by TomoTherapy Inc. Four or five alanine dosimeter pellets were used per measurement position. The NPL alanine dosimeters were read out using a Bruker EMX spectrometer, and the ZNA-Middelheim alanine dosimeters were read out using a desktop Bruker EMS-104 spectrometer. **Results:** In the target volume, ion chamber and alanine doses agreed to better than 2%. The statistical uncertainty in absorbed dose measured using a single alanine pellet was 0.06 Gy at NPL and 0.3 Gy using the desktop spectrometer. On average, absorbed dose measured using the ZNA-Middelheim alanine system was 3% higher than the dose measured using the NPL alanine system. **Conclusions:** Dosimetry audit of IMRT delivered by helical tomotherapy using alanine/EPR is both

convenient and independent of the assumptions made in analysing ion chamber measurements.

SU-FF-T-196

Dosimetry for Linear Sources in Heterogeneous Prostate Phantom

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Purpose: To characterize the light distribution from linear diffusing optical fibers in a prostate-simulating phantom. The light distribution depends on the geometry and optical properties of the phantom and on the geometry of the light sources. Light distributions were measured in homogeneous and inhomogeneous phantoms. **Method and Materials:** Measurements were performed in homogeneous and inhomogeneous prostate simulating phantoms with linear light sources of lengths (1 – 5 cm) placed in the phantom through transparent catheters. The optical fluence rate was measured using isotropic detectors at various distances from the linear source using a computer-controlled stepper motor. Results for a point source were also presented to predict the light fluence rate for linear sources with the intensity distribution of the linear sources taken into account. Attempts were made to predict the light fluence rate distribution in 3D using calculation with a kernel-based method. **Results:** The profiles of linear sources with lengths between 1 and 5 cm were scanned at 0.3, 0.5 and 0.7cm away using isotropic detectors in homogeneous and inhomogeneous phantoms. The increase of light fluence in lower absorption region in an inhomogeneous phantom is due to the increase of effective optical penetration depth. Scans measured around a 5cm linear source show a clear difference in optical properties for the case when the detector passes through the urethra, prostate tissue and tumor. **Conclusion:** We have demonstrated the ability to characterize the light distribution inside the prostate using a methodology compatible with clinical measurement. Our method is sensitive enough to differentiate between the optical properties of the prostate, tumor and urethra in our model system.

SU-FF-T-197

Dosimetry in a Lung Moving Phantom

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Purpose: Respiratory organ motion is known to be one of the largest intrafractional organ motions. In the lung phantom, secondary electron transport in addition to the photon transport tends to extend the dose disequilibrium region, resulting in a larger penumbra region and thus potentially different motion effect on dose distribution for IMRT fields. This study quantifies the effect of motion on dose distribution in lung medium. **Method and Materials:** Measurements were performed in a water-equivalent made of solid water and a lung phantom composed of 15-cm thick 0.25 g/cm^2 cork slabs at several depths a computerized motion phantom. Dose distributions for 6 MV and 15 MV photon beams are measured for a 10x10 cm^2 open field and for IMRT fields. The motion is created using a ±1-cm motion amplitude and 6 second per breathing cycle. EDR2 films were used to determine the dose distribution with or without motion at various depths in the solid and lung phantom. **Results:** At 10 cm depth, the penumbra of dose profile in the lung phantom is much broader than the solid phantom. The penumbra width increases with increasing photon energy. The effect of motion can be modeled with a motion kernel determined by the probability function of the breathing cycle and is independent of the phantom (solid or lung) types used. At 2.5 cm depth, the penumbra width between the lung and solid phantom is similar since the same solid water material was used above the point of measurement. **Conclusion:** We have shown that dose distribution in a moving lung phantom can be predicted from the measured dose distribution in the static lung phantom and a motion kernel. The introduction of secondary electron transport actually reduces the effect of motion on the dose distribution because the penumbra width is wider in lung material.

SU-FF-T-198

Dosimetry of Small Lung Lesions with EGSnrc Monte Carlo and Treatment Planning Systems

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Background: The ability to deliver a homogenous dose distribution to small lung lesions is usually affected by the surrounding less dense normal lung. In low-density tissue, there is increased transmission of photons relative to that in tissue. The lateral scatter of electrons out of the beam can lead to loss of field flatness and increased penumbral width. The magnitude of these effects is known to be very significant at high energies. Some commonly used radiotherapy treatment planning systems have had limited success in predicting accurately the dose distribution under these inhomogeneous conditions. **Purpose:** The purpose of this work is to study the magnitude of these effects using the EGSnrc/BEAMnrc Monte Carlo code on a typical patient CT dataset and to assess the limitations in treatment planning of such lung tumours with three Treatment Planning Systems (TPS); ADAC Pinnacle III v7.4, Varian Eclipse IMX and MDS Nordion Theraplan Plus v3.8. **Methods:** Small lung tumours (GTV) of diameter (3cm and 5cm) were simulated as water equivalent volumes and graphically inserted into the CT dataset at three different locations (Anterior, Central and Posterior) in the right lung. Using 6MV and 15MV beams, modelled for a Varian 21EX with the BEAMnrc Monte Carlo dose distributions were simulated using a Parallel Opposed Pairs (POP) technique. The field sizes were varied such that the distance from GTV to field edge was 1.0cm, 1.5cm and 2.0cm. **Results and Discussion:** Compared to the Monte Carlo calculated dose distribution, considerable and unique differences were observed in predicted dose by the TPS around the periphery of tumour and in the lung. These differences can be attributed to changes in the electron transport in lung, which are not adequately taken into account. The severity of these uncertainties, increases with photon energy, and decreases with field size for all planning systems.

SU-FF-T-199

Dosimetry Validation for Spinal Cord Irradiation In Extracranial Stereotactic Radiosurgery

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Purpose: A single large dose in the range of 16 to 20 Gray at 90% isodose line can be safely delivered to solitary or multiple metastases in the vertebral column via extracranial stereotactic radiosurgery. However, the spinal cord dose is usually limited to 10 Gy within the treatment segment. Thus, the dosimetry validation for the spinal cord is critical for this procedure and for further dose escalation. **Methods and Materials:** Bearing the challenges of the great dose gradient and irregular shape of the target around the cord, we have designed an experiment to measure the absolute dose to the cord using a farm chamber placed at the location of the spine cord inside the solid water phantom. The air-cavity of the chamber is precisely delineated in the iPlan system (BrainLAB) and dose volume histogram for the air cavity was used for calculating the effective dose in the treatment plan. This can then be compared with measured doses by the chamber. Isodose distributions in two coronal planes through the center of tumor and through the cord are also measured with EDR2 films and compared with the planned dose distributions. **Results:** Our tests demonstrated that this dosimetry measurement is reliable with high accuracy and precision of < 3% deviation in such difficult dosimetry verification. Results from five spinal SRS cases show that the cord doses with IMRS plans are within 5 % from those of the treatment planned doses. Importantly, the isodose distributions at the cord and near the target volume are consistent with the planed dose distributions. **Conclusions:** The small discrepancies (up to 5%) for the absolute dose measurement show no gross errors in the dose delivery and dose calculation using a pencil beam algorithm in the planning system.

SU-FF-T-201

Effect of Mini-Phantom Material On In-Air Dosimetry Quantities

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Purpose: Recent studies suggest that miniphantom material and thickness affect the measured values of in-air output ratio. These results prompt us to investigate the effect of mini-phantom depth and material on several in-air quantities. **Method and Materials:** Beam data for two photon beams (6x and 15x) were compared for several in-air quantities: off-axis ratio (OAR); central axis wedge factor (CAX WF); distance factor (DF) dependence and off-axis wedge factor (OAX WF). Several miniphantom materials (Lucite, copper, lead and graphite) were used with a radiological depth ranging from 2 to 25g/cm^2. **Results:** OAR decreases with increasing mini-phantom thickness and off- axis distance x, for the same mini-phantom material. For open field, the maximum difference is 5% and 8% for 6x and 15x, respectively. CAX for WF were measured for 15^0, 45^0 and 60^0 wedge angles, for both virtual and solid wedges. WF increases up to 11% with mini-phantom thickness, when solid wedges are used. Virtual wedges have an effect of less than 1% on WF. Maximum errors were found for 45^0 solid wedge. DF dependence was measured for several SAD's for 6 and 15x, open and 60^0 virtual and solid wedges. DF agreed within 3% regardless of beam energy, material and SAD. OAX WF were measured at a few off-axis points along both wedge and non-wedge gradient directions for 6x. WF varies by up to 2.6% in the toe direction, by up to 1.1% in the heel direction and by up to 3.3% in the non-wedge direction. **Conclusion:** Mini-phantom material has an effect on measured in-air dosimetric quantities. Ideally, a water-equivalent miniphantom should be used. When the miniphantom thickness increases (even for water equivalent material), the value of WF, OAR, DF increase by 11%, 8%, 3%, respectively. The error also increases with Z value of mini-phantom and photon energy.

SU-FF-T-202

Effect of Motion On Dosimetry in IMRT Fields

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Purpose: The clinical implementation of IMRT, particularly for tumors of the thoracic cavity, may be complicated by the effects of breathing motion. We present an experimental evaluation of the effects of a sinusoidal breathing cycle on the dose delivered by IMRT plans. **Method and Materials:** A series of phantoms were placed on a wheeled cart connected to a computer-controlled step motor. The motor was moved with constant angular velocity, causing approximately sinusoidal motion of the phantom in the superior-inferior direction. The amplitude of the oscillation was 1 cm. The frequency of oscillation was matched to a 4 second breathing cycle. We measured the effects of this motion in open beams and IMRT fields in using films in the transverse and coronal planes, and with an ionization chamber at isocenter. **Results:** Dose profiles measured in a 10 x 10 cm open beam with a film placed at a depth of 10 cm in the horizontal plane confirm that the dose measured in the moving phantom is accurately modeled by the convolution of the static dose with an analytically determined motion kernel, despite the 20% change in dose induce by the motion in the penumbra region. When IMRT fields are delivered to the moving phantom, the change in the dose at isocenter varies, but is typically less than 5%. The variation at other points in the treatment region, however, is often much larger. The convolution model accurately predicts these changes except for regions dominated by small segments. **Conclusions:** We have demonstrated that the effects of sinusoidal oscillatory phantom motion on dosimetry in open beams and IMRT fields can be measured experimentally, and can be accounted for using a motion kernel convolution. Motion may lead to significant errors in dose delivery, particularly for tumors in the lung and thoracic cavity.

SU-FF-T-203

Effect of Non-Uniform Source Strength On I-125 Prostate Implant Dosimetry

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Purpose: The current quality control policies in brachytherapy recommends assaying at least 10% of the seeds and source strengths uniformity should not be greater than 3% in those assayed seeds. In real clinical cases, the un-assayed seeds from the same batch may have larger source strength non-uniformity. In this study, we investigated the effect of non-uniform source strength on ^{125}I prostate implant dosimetry. **Method and Materials:** Ultrasound images were obtained from volumetric measurement; those images were digitized into TheraPlan Plus planning system (Nucletron) for calculation with uniform source strength. A clinical pre-plan was approved and used as reference plan. AAPM TG43 dosimetric system was used for dose calculation throughout the study. While keeping seed positions fixed, the iodine-125 seeds were assigned different source strength sampled from four normal probability distributions with 5%, 10%, 20% and 30% standard deviation centered on mean source strength respectively. The pre-plan was then recalculated with sampled seed strength and the V200, V150 and V100 were compared with those of the original pre-plan with uniform seed strength. **Results:** The maximum change from 5 patients for V100 is -0.4%, -0.8%, -1.4% and –3.3% for normal probability distribution with 5%, 10%, 20% and 30% standard deviation respectively when compared with uniform source strength plans. For V150 the maximum change is –2.6%, 4.0%, -5.1% and 20.1%. And for V200, the maximum change is –3.5%, -5.9%, -8.9% and 31.8% respectively. **Conclusion:** V100 changed less than 3.5% with 30% source strength non-uniformity; implying V100 was not sensitive to source strength distribution. V200, V150 and V100 changed less that 4.0% with 5% source strength non-uniformity. With a source strength non-uniformity of 5%, its effect on ^{125}I prostate implant dosimetry was not significant. Evaluation of DVHs for urethra, rectum wall and location of hotspot were still underway.

SU-FF-T-204

Effect of Voxel Size On Monte Carlo Dose Calculation for Intensity Modulated Radiotherapy Treatment Planning

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Purpose: In radiotherapy treatment planning, the voxel size plays a role in each step, from the structure contouring, beamlet calculation, treatment optimization to plan analysis. Large voxels may affect the planning accuracy while small voxels will increase computation time significantly. The choice of voxel size is a compromise between planning accuracy and computation speed. This work investigates the effect of voxel size on the accuracy and computational speed of Monte Carlo based treatment planning for IMRT. **Method and Materials:** Selected patients with various treatment sites were scanned on a CT simulator and the CT data with RT structures were converted to patient geometry files with different voxel sizes for Monte Carlo simulations. Comparisons of the structure volume, beamlet dose distribution, plan optimization, DVHs and dose distributions were made with different voxel sizes. Target and critical structures with small volumes, such as the optical nerves in head and neck cases, were specially considered in the comparison. **Results:** In Monte Carlo IMRT planning, differences in the open-field dose calculations prior to the optimization process using different voxel sizes (4 x 4 mm^2 and 2 x 2 mm^2) were usually small. However, the results from the optimization showed that different voxel sizes could generate different beamlet weights resulting in different treatment plans. The effects could be clinically significant. For the same IMRT plans, the effects of voxel sizes in the dose and DVH calculations vary depending on the treatment sites, anatomy and target/organ volume. Small voxel sizes (1-2mm) are necessary for small structures in and near heterogeneous geometries such as in the head and neck regions. **Conclusions:** The effect of voxel size on dose calculation and plan optimization can be clinically significant in IMRT treatment planning. Small voxel (1-2mm) should be used for head and neck cases.

SU-FF-T-205

Effects of Intra-Fraction Motion On IMRT Treatment with Segments of Few Monitor Units

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Introduction: Intra-fraction motion can affect the delivered dose distribution in radiotherapy. This is a concern in IMRT because of potential interplay between the delivered fluence pattern and the patient's breathing pattern. A widely applied approach to model organ motion is the use of a probability density function (pdf) in IMRT-optimization. We assess if breathing compromises treatment with IMRT segments delivering only few monitor units (MU), where the delivery time of the segments will be of the order of the breathing period. Further, we assess the limitation of IMRT-optimization based on pdfs for incorporating organ motion in treatment planning. **Methods:** A motor-driven platform, which moves

sinusoidally with a user-specified amplitude and a period of 4s for tumor motion was used. The measurements were performed for motion amplitude of 4cm in $4x4cm^2$-$10x10cm^2$ open fields and dose-rate of $500MUmin^{-1}$. The MUs delivered were 8 to 183MUs, corresponding to delivery times of 1s to 22s. The measurements were repeated for ten different initial phases. **Results:** The delivered dose to a moving target varies with initial phase and with segment delivery time. For very long segment times the delivered dose has a 1-2% spread with the initial phase. Therefore, over 30 fractions, the average dose delivered to the moving tumor will converge to the mean dose delivered over the breathing-period. For short delivery times, the delivered dose varies significantly with the initial phase. This is because the delivered dose becomes dependent on non-uniform dose and penumbra effects. **Conclusion:** Motion can compromise an IMRT treatment if the segment delivery time (1-12s) is of the order of the breathing period and motion occurs in a region of non-uniform dose. Since the delivered dose also depends strongly on the initial phase, for short delivery times, care is needed when modeling organ motion as a pdf in IMRT optimization.

SU-FF-T-206

Effects of Static Dosimetric Leaf Gap On MLC-Based Small Beam Dose Distribution for Intensity Modulated Radiosurgery

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Purpose: To evaluate the impact of static dosimetric leaf gap on MLC-based small beam dose distribution and to compare the calculated results from planning system with actual measurement for intensity modulated radiosurgery. **Methods and Materials:** We determined the optimal dosimetric static leaf gap by comparing the profiles of MLC based small beam with those of the collimated fields. The applied leaf gaps were 0, 1, and 2 mm for comparison. The doughnut shaped PTV (6.1 cm^3) and inner OAR (0.3 cm^3) were delineated for delicate intensity modulated radiosurgery test plan. For the test, Millennium 120 leaf MLC and Eclipse Radiation Therapy Planning system (Varian) were used. For the measurement of dose, we used radiosurgery head phantom (model 605, CIRS, Norfolk, Virginia). **Results:** We found that 2 mm gap was optimal for the MLC based small beam. The maximum dose differences at the inside PTV, outside PTV, and inner OAR were 22.3%, 20.2%, and 35.2% for the 0 mm leaf gap, 17.8%, 22.8%, and 30.8% for the 1 mm leaf gap, and 5.5%, 8.5%, and 6.3% for the 2 mm leaf gap, respectively. In a humanoid head phantom study, the final dose distribution from the Eclipse planning system was significantly different from the measured values. The planned results were similar, while the measured showed large differences in dose according to the leaf gaps (range: 1.3 – 12.7%). **Conclusion:** An inadequate determination of the dosimetric static leaf gap during the RTP configuration can make errors from the final dose calculation, which can sometimes be confused with unwanted QA results of IMRS. An appropriate dosimetric leaf gap setting is critical during the commissioning of an inverse planning system and an incorrect setting can produce large dose delivery errors particularly in the delicate IMRS treatment.

SU-FF-T-207

Efficient IMRT Delivery -- Fast Generation of Integer-Valued Beam Profiles

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Purpose: The delivery time for an intensity-modulated radiotherapy plan using the step-and-shoot method may be impractical for complex beam profiles that require a large number of segments. We propose a fast algorithm that simplifies beam profiles to integer-valued intensities, which results in dramatic reduction of leaf-segments, while maintaining the ``goodness" of the original-optimized-plan. **Method-and-Materials**:An optimization model was designed to simplify a beam profile to integer-valued intensities. The user specifies the permitted intensity level values, the maximum number of intensity levels, and the acceptable percentage of total under-/over-dosage. The model minimizes the absolute difference between each beamlet intensity and a weighted average of the intensities of the beamlet's nearest neighbors(and itself) in the resulting plan. The method is tested on several cases of head-and-neck and prostate cases, each with seven beams. In the original-optimized-plan, the number of intensity levels in each beam ranges from 97 to 153. **Results:** For all beams, an optimal integer solution was obtained within 15seconds. This held true even after the total intensity delivered by the simplified-beam-profile was constrained to be either the floor or ceiling of the total intensity of the original beam profile(the tightest possible). The simplified-beam-profiles were permitted to use up to ten distinct integer values(between 1-20). There is virtually no difference in conformity, homogeneity and dose distribution in PTV(all within 0.02%), as well as in all OARs. The total intensities deposited between the original-optimized-plan versus the resulting simplified plans are within 0.45%. Running through Siochi's leaf-sequencer, the resulting segments reduce from 89-151 to 14-39 for all simplified plans. **Conclusions:** This work indicates the potential of a quick algorithm for simplifying complex intensity profiles while maintaining good plan quality. The resulting beam complexity reduction improves deliverability of the leaf sequence of each beam. The algorithm takes only seconds to complete, thus making it realistic for clinical implementation.

SU-FF-T-208

Efficient Selection of Beam Number and Orientations for Intensity Modulated Radiotherapy (IMRT) by Emulating An Ideal Dose Distribution

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Purpose: Since radiotherapy treatments only utilize a limited number of beams, it is important that these beams be carefully selected to extract maximum benefit. Here we propose a novel, fast, scheme that selects beam number and orientations for IMRT with the goal of emulating an ideal dose distribution resulting from a very large number of beam orientations. **Method and Materials:** The procedure starts by optimizing IMRT fluences for a large number of beam orientations (ideal dose distribution). A subset of these orientations is then sequentially selected to emulate this ideal distribution, using an orthogonal QR factorization method (dose-volume constraints are respected). The use of QR factorization, rather than a full optimization, makes the process time-efficient. During the procedure, previously selected beams are replaced by beams that are more capable of emulating the ideal distribution. The number of beams is chosen as that above which there are only marginal gains in a least-squares objective function. The procedure was tested on a head-and-neck case (non-coplanar orientations) and a prostate case (coplanar orientations). **Results:** For the head-and-neck case, the objective function (normalized to 1 for the ideal distribution) decreased with increasing orientations as: 14.43 (3 beams), 9.26 (4), 2.59 (5), 1.81 (6), 1.64 (7). Beyond 6 beams, objective function gains are marginal. The actual plan used to treat this patient yielded a 455% higher objective function, for the same number of beams (6). For the prostate case, the corresponding numbers were: 1.69 (3 beams), 1.30 (4), 1.15 (5), 1.11 (6). In this case 5 beams appear sufficient. The actual clinically used beams were 6% higher (5 beams). Computer time was on the order of 1 -3 hours on a 1 GHz laptop processor. **Conclusion:** The procedure presented here shows great promise in extracting greater benefit from IMRT by optimizing beam number and orientations.

SU-FF-T-209

Electron Arc Therapy with An Elekta SL-25 10 MeV Beam Using a Dedicated Short Applicator

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Purpose: To implement the electron arc therapy with an Elekta SL-25 10 Mev beam using a dedicated short applicator. **Method and Materials: .** All measurements were done on an Elekta SL-25 with a 10 MeV electron beam. Radial PDD were characterized for 4 different cylindrical acrylic phantoms using TLDs and Kodak X-Omat-V radiographic films The phantom radius (d_i) ranged between 5.1 and 15.2 cm, the total arc angles (α) varied between 60° and 160° and the number of monitor units (MU) per degree between 0.5 and 7. The field with at isocenter (w) was varied between 3.7 and 9.8 cm. Based on this data bank, an analytical model was developed for monitor unit (MU) calculation. This model estimates arc beam output at the depth of maximum dose (d_{max}) as a function of d_i and α for a given w. A verification of the model precision was done with a new cylindrical phantom. **Results:** Curve fitting of the complete set of beam output data with w fixed at 7.3 cm was done with an asymptotic

relationship between the dose rate at d_{max} and the inverse square of d_i. The dependence of the beam output on α was introduced by assuming an explicit function of α for each parameter of the model. Results show that the calculated beam output data is a good approximation for all measured data for all phantoms and arc angles: 89% of the calculated values are within ± 3% of the measured ones and all points are within a ± 5% error range. **Conclusion:** From our results, clinical implementation of the electron arc therapy technique is possible and should be facilitated by the use of our predictive model in the treatment planning process.

SU-FF-T-210

Electron Beam Dosimetry Using a Computed Radiography System

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Purpose: To investigate the ability of the Kodak 2000RT computed radiography (CR) system to accurately measure electron beam isodoses. **Method and Materials:** The Kodak 2000RT CR reader and Agfa MD-10 CR plate were used to measure electron beam dose distributions and the results were compared to EDR2 film. The film was scanned by a Vidar dosimetry Pro scanner. The CR plate or film was oriented either perpendicular or parallel to the electron beam. Electron energies of 6, 12, and 20 MeV were used, delivered by a Varian 2100C. Field sizes of 4x4, 10x10, and 25x25 cm square were used. Calibration of the CR plate or film was performed with perpendicular and parallel irradiation techniques for comparison. Calibration curves as a function of beam energy and field size were compared between CR and film. **Results:** The CR system was able to reproduce electron beam isodoses spatially within 2mm of those from film. CR is very sensitive and easily demonstrates the x-ray contamination beyond the range of the electrons. CR dose response differences were found between parallel and perpendicular irradiation geometries but little difference as a function of energy or field size. **Conclusion:** The Kodak 2000RT CR system is capable of accurately measuring dose distributions from electron beam irradiation. **Conflict of Interest:** This work was supported by Eastman Kodak.

SU-FF-T-211

Energy and Intensity-Modulated Radiation Therapy Using Protons. To Optimize Or Not to Optimize?

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Purpose: Development of a robust and time efficient 3D beam scanning technique in proton therapy opened up a possibility for utilizing particle beams for intensity-modulated radiation treatments. Just like for conventional inverse-planning using photons, an intensity-modulated technique for protons would also require performing time-consuming beamlet optimization calculations ultimately leading to laborious intensity-modulated beam delivery process. The purpose of this study is to show that with a "wise" choice of beam orientations, determined from the requirement that a given beam traverses as little volume of critical structures as possible, it is feasible to achieve superior patient dose distribution without resorting to time-consuming optimization procedure. **Method and Materials:** Monte-Carlo calculations using track-repeating technique were used to perform comparative studies between proton plans that involve inverse optimization calculations and those that are based only on a forward planning. The energy modulation calculations that allow delivering constant dose distribution throughout the depth extent of the target were carried out in both delivery methods. Two clinical cases of lung and head-and-neck tumors were chosen to perform this study. **Results:** We have inter-compared the dose distributions between intensity-modulated and forward based planning techniques for proton beams for two different clinical lesions. The distribution of isodose lines and DVH histograms for both methods suggest that with intelligent choice of the beam numbers and beam angles it is possible to generate patient dose distribution that is comparable to that obtained from the inverse treatment planning optimization. **Conclusions:** Because of the possibility to modulate the dose in the depth dimension for proton beams, it is feasible to achieve superior dose distribution without resorting to time-consuming inverse planning. This suggests that the intensity modulated optimization calculations may not need to be employed for proton beam treatment planning.

SU-FF-T-212

Energy Response of a CR Plate Exposed to Megavoltage X-Ray and Electron Beams

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Purpose: To investigate the mechanism underlying the energy dependence when a CR plate is exposed to therapeutic beams. **Method and Materials:** Small circular disks were cut from one CR plate and placed in a water-equivalent plastic (WEP) phantom and exposed. The photostimulated luminescence (PSL) signal was recorded until the signal dropped to the background level to obtain the bleaching curve (PSL vs. time). The area under the bleaching curve (AUC) gives a measure of stored information in the CR plate. Monte Carlo simulations were used to obtain the ratio, D_{CR}/D_{Water} of the energy absorbed in the active layer of the CR plate in a WEP phantom to the energy absorbed in water when the entire phantom (including the CR plate) is replaced by water. **Results:** For electron beams, the AUC was independent of energy for any given dose to water, and the work function, W, i.e. the energy required to produce one PSL photon was also energy independent. In contrast, for photon beams, the AUC was 15% and 30% higher for 18 MV than for 6MV and Co-60, respectively where the ratio D_{CR}/D_{Water} was 0.81, 1.08 and 1.11, respectively. Taking AUC data into account, the W for 18 MV had to be lower than for 6MV and Co-60, our data showing 37% and 45%, respectively, in order to give a higher AUC despite a lower energy absorption in the active layer. While there is no obvious reason for this energy dependence, the differences in the secondary electron spectra produced by the different photon beams are probably not responsible.**Conclusion:** The method presented here will help researchers to both understand the response to ionizing radiation and develop new applications such as megavoltage dosimetry for IMRT verification. The energy dependence of W on beam modalities requires caution regarding CR dosimetry.

SU-FF-T-215

Estimation of Whole Body Dose During the Delivery of Step-And-Shoot Intensity Modulated Radiation Therapy

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Purpose: To investigate whether the increase in the number of monitor units required to deliver IMRT results in a significant increase in the whole body dose to the patient. **Method and Materials:** IMRT and conformal plans were constructed using Nucletron MasterPlan for head and neck and prostate tumours. The anthropomorphic phantom RandoMan was used as a dummy patient. TLD 100's were placed along the central axis of the phantom in 5cm intervals and the whole body dose was then measured for all plans. In addition, the effective whole body dose was calculated for the head and neck plans using NCRP report 116.
Results: The number of monitor units required to deliver a cGy to the isocenter was up to three times greater for the IMRT plans in comparison to the conventional conformal plans. A significant increase in whole body dose was observed when comparing 15MV IMRT prostate plans with the conformal prostate plan. The 6MV prostate plans showed no significant increase in whole body dose due to the lack of neutron production at this energy. The calculated whole body effective dose per Gy delivered to the isocenter for the head and neck plans was 6.23mSv, 5.12mSv and 4.27mSv for the nine field IMRT, seven field IMRT and conventional conformal plans respectively. **Conclusion:** The 15MV prostate plans should be avoided where possible as they lead to a significant increase in whole body dose. Due to the larger treatment field with the conformal head and neck plan, the scatter leakage along the patient is greater for the conventional plan than the IMRT plans up to 40cm from the isocenter, beyond this the head leakage becomes dominant and the dose from IMRT plans is greater. The whole body effective dose is lower for the IMRT head and neck plans than the conformal plans.

SU-FF-T-216

Evaluation and Commissioning of K&S Associates Inc. Diamond Monitor Unit Calculation Software

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Purpose: To report on the evaluation and commissioning of the Diamond (K&S Associates Inc., Nashville, TN) monitor unit (MU) calculation software. **Method and Materials:** Based on clinical dose-response studies, the ICRU states that dosimetry systems must be capable of delivering dose to an accuracy of 5%. The accurate determination of dose per MU to a point within the patient is an essential part of this process. Good clinical practice dictates that MU obtained from the treatment planning system (TPS) be checked using an independent system. Diamond is a windows-based computer program for computing beam on time for radiation treatments. The software is used for quality assurance purposes to confirm MU produced by our TPS, Pinnacle^3 (Philips Medical Systems, Andover, MA). To ensure that the Diamond MU calculation algorithms are correctly implemented in our clinic, the algorithms were verified by comparing point of interest dose values calculated by Diamond, with dose values calculated using the Pinnacle^3 TPS, and in-house developed photon and electron MU calculation software. The in-house software, which has been used in our clinic for several years, has been extensively tested against measured data. The tests cover a variety of square, rectangular, and blocked fields at several depths. Standard electron and photon energies for both Varian and Siemens linacs were tested as part of the commissioning process. These comparisons were implemented in a variety of clinically relevant test cases. **Results:** Results indicate that Diamond calculated MU values are within 2% of the in-house developed MU calculation algorithms for electron and photons. Only a few calculations showed disparities of greater than 1%. **Conclusions:** Based on our testing and analysis of calculation methods, we are satisfied with the Diamond MU calculation software. We are currently in the process of evaluating the intensity modulated radiation therapy module of this software.

SU-FF-T-217

Evaluation and Validation of GATE-Based Absorbed Dose Calculation for 3D Patient-Specific Internal Dosimetry

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Purpose: The objective of this study is to validate the use of GATE Monte Carlo simulations to determine patient-specific dosimetry using quantitative multi-modality imaging. **Method and Materials:** Data acquired with the Symbia ™ hybrid SPECT/CT system are reconstructed with Flash-3D™ and corrected for scatter, collimator detector response and attenuation using a CT attenuation correction method. The voxel-based CT model is used with GATE to compute 3D dose distributions from the SPECT data. Validation is performed using both simulated SPECT data and anthropomorphic phantoms. **Results:** Initial validation studies show that GATE, while time consuming, is suitable in dose calculation. **Conclusions:** The approach presented can be used for radionuclide multi-modality dosimetry leading to patient-specific dose calculations for treatment planning.

SU-FF-T-218

Evaluation of a New Computational Technique for Photons and Electrons

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Purpose: To demonstrate the preliminary results of a new computational technique which computes high accuracy transport factors for patient/phantom specific parameters and to use these transport factors to compute energy deposition independently for photons and electrons **Materials and Methods:** During treatment planning the transport factors are loaded into RAM and used to directly compute a first principle high speed, high accuracy solution. Presented below are planning phase equations that are iterated upon using pre-computed transport factors: 1. Double Differential Photon Scatter

$\Phi p(E',\Omega',r) = \int_{\Omega}\int_{E} \Sigma s(\Omega\rightarrow\Omega', E\rightarrow E', r)\, \Phi p(E,\Omega,r)\, dE\, d\Omega$

In our equations, Φ is particle flux, r position, E energy, Ω is the solid angle and Σs are the scattering cross section.

2. Explicit Photon Transport – Problem Specific

$\Phi p(E,\Omega,r') = \int_{V} \Phi p(E,\Omega,r)\, Tp(E, \Omega, r\rightarrow r')\, dr^3$

The Compton scattered photons are transported explicitly using pre-computed transport factors.

3. Photo-Electron Scatter

$\Phi e^{-}(Ee^{-},\Omega e^{-},r') = \int_{\Omega}\int_{E} \Sigma sp\rightarrow e^{-}(\Omega\rightarrow\Omega e^{-}, E\rightarrow Ee^{-}, r)\, \Phi p(E,\Omega,r)\, dE\, d\Omega$

Electrons from photon interactions are modeled in accordance with their angular and spatial distribution. Local photon scatter interactions are used to determine the electron source distribution from a double differential scatter matrix $\Sigma sp\rightarrow e^{-}(\Omega\rightarrow\Omega e^{-}, E\rightarrow Ee^{-}, r)$.

4. Electron Transport to dose

$D(r') = \int_{V} \Phi e^{-}(Ee^{-},\Omega e^{-},r)\, Te^{-}(E, \Omega, r\rightarrow r')\, dr^3$

The final dose distribution D(r') from electron transport is determined using pre-computed phantom/patient specific transport factors. **Results:** Preliminary calculations with 2.5 mm voxels indicate that application of this model obtains fast, high accuracy results for clinical radiation treatment machines in various media. Preliminary research indicates considerable speed improvements over Monte Carlo without degrading accuracy. **Conclusions:** This new code utilizes an innovative process to improve computational speed and accuracy for dose calculations in radiation treatment planning. Patient specific data is used to compute high accuracy transport factors. These factors are used independently for photons and electrons to calculate dose deposition.

SU-FF-T-219

Evaluation of a Practical and Low Cost Gafchromic Film/flat-Bed Scanner Combination for Planar Dosimetry

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Purpose: To assess the accuracy and practicality of using GAFCHROMIC® EBT Film in combination with an Epson flat-bed scanner for the verification of advanced treatment techniques in radiation therapy. EBT is a new type of Gafchromic film with high sensitivity to ionizing radiation. The combination of EBT with flat-bed scanner represents a very low cost and convenient dosimetry system. Methods and Materials: Experiments were conducted to evaluate two aspects of the EBT/flat-bed-scanner combination. First the stability of the scanner was evaluated by repeat scanning, over several weeks, of a conventional Kodak XV film, which is known to be highly stable post-irradiation. Second the dose response and stability of EBT film was investigated by repeat scanning, over several weeks, of EBT film pieces irradiated to different doses (0 to 8Gy with 6MV photon beam). **Results:** The reproducibility of the Epson scanner was found to be highly stable, to within 1.03%, over all ranges of OD studied. A slight non-uniformity in background was observed, but this background was consistent enabling efficient correction. The dose response was observed to be highest in the red channel of the scanner. The dose response curve of EBT film was found to be non-linear but stable (within 1.32%) within one week after irradiation. **Conclusions:** The Epson® 4990 Scanner/ GAFCHROMIC® EBT Film dosimetry combination appears a promising, low-cost, and highly convenient dosimetry system for radiation therapy.

SU-FF-T-220

Evaluation of a Prototype Thermoplastic Mask Using the Novalis Body System

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Purpose: To measure interfraction setup uncertainty of patients undergoing IMRT treatment who are immobilized by a prototype reinforced thermoplastic mask. **Methods and Materials:** Two mask designs are utilized depending on the anatomical location of the lesion. To validate patient setup before each treatment fraction, the Novalis Body/ExacTrac system is used. That system uses optically imaged infrared (IR) retroreflectors as well as kilovoltage x-ray imaging to verify patient setup. Patients were immobilized with the Orfit HP IMRT immobilization system, and IR markers were placed anteriorly on the prototype mask. Patients were scanned with a Philips ACQsim CT, and the image set was transferred to BrainScan TPS where the IR markers are identified and a plan is created. The plan is then tranferred to ExacTrac. The patient is initially setup using the IR markers. Two kV x-rays images are taken and

fused to the corresponding DRRs generated from the reference dataset used for planning. The patient is moved into position and treated based on the shifts generated from the fusion transformation. The on-going study currently has seven patients with a total of 99 treatment fractions. **Results:** The average x-ray shift and maximum deviation for each patient will be profiled. The current results show an average vertical, longitudinal, and lateral magnitude of 0.98 mm, 0.96 mm, and 1.02 mm, respectively with a standard deviation of 0.49 mm, 0.65 mm, and 0.64 mm. The maximum observed shift was 4.92 mm and is accredited to a cephalad lesion where there was poor image contrast which affected the fusion quality. **Conclusion:** This system adequately immobilizes the patient and constrains interfraction setup uncertainty to within two millimeters for most patients. At our institution, this immobilization system is used to treat lesions proximal to critical structures. Conflict of Interest: **The masks were provided by Orfit Industries, Belgium.**

SU-FF-T-221

Evaluation of An Electron Monte Carlo Dose Calculation Algorithm for Electron Beam Radiotherapy

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Purpose: To systematically evaluate the electron Monte Carlo (eMC) dose calculation algorithm of the Eclipse treatment planning system and to identify factors that affect its calculation accuracy. **Method and Materials:** Percent depth dose (PDD) and profiles for each electron energy/applicator/depth combination were measured for four Varian Clinac 21EX Linacs. Cutout factors for various cutout sizes down to 3x3 cm^2 were also measured. Statistical comparison between eMC calculation and measurement was performed for parameters such as shift in depth of PDD curves, field size, penumbra width, average dose difference within 80% of field size, beam symmetry, Bremsstrahlung dose, and cutout factor. Analysis of variance was used to identify factors that have significant influence on the observed discrepancies. **Results:** The agreement between measured and calculated 50% PDD depth was within ±2 mm for nearly all machine/energy/applicator combinations except the 6x6 6 MeV beams on three machines where maximum difference was 3.8 mm. The calculated field width was larger than that of measured in most of the cases but within 3%. The differences between calculated and measured penumbra were also within 3%. The calculated Bremsstrahlung doses were smaller than measurements, with a few exceptions. Analysis of variance identified machine as a significant variable for the observed discrepancies in PDD, field width, and penumbra, suggesting possible variations among linacs or the quality of measured data. Calculation grid size was found to have significant effect on calculation accuracy. Using grid size of 5 mm resulted in approximate 10% discrepancies. Reducing grid size yielded significant improvement on the calculated cutout factor: from 5% discrepancy to less than 3% when grid size of 1 mm was used. **Conclusion:** The overall agreement between the eMC calculation and measurements was acceptable. Calculation grid size of 2.5 mm or smaller is recommended for all field sizes for eMC algorithm.

SU-FF-T-222

Evaluation of Commercial QA Software for Independent IMRT Dose Calculations

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Purpose: To evaluate the use of IMSure QA software for IMRT dose calculations by comparison with experimental ion chamber measurements. **Method and Materials:** IMSure QA software (Standard Imaging) was used to calculate dose to isocenter for 80 dynamic IMRT patient plans: 50 prostate IMRT plans and 30 head and neck IMRT plans. The results were compared with patient-specific QA measurements where dose was measured in a 16x30x30cm solid water phantom using an Exradin A14 ion chamber. Plans were specifically chosen to include as large a fraction as possible that either failed our 3% criteria for agreement with ion chamber, or marginally passed it. **Results:** Agreement between IMSure and ion chamber measurements was -0.8% ± 1.5% (overall agreement range -3.7% - +3.6%) and 0.2 ± 2.0% (range: -4.2% - +5.6%) for the prostate and head and neck cases, respectively. This is similar to agreement between Eclipse and ion chamber for the same patient group, which was 1.0±1.5% and 0.1±2.1%. Based on 3% pass/fail criteria, IMSure correctly identified 5 of 9 prostate cases that failed the ion chamber measurement, and 1 of 5 head and neck cases. This gives an overall true positive rate (failures correctly identified) of 43%. IMSure also incorrectly identified 1 prostate and 2 head and neck cases (from 66 cases which passed the ion chamber QA) as failures, giving a false positive rate (passes identified as failures) of 5% for this set of plans. **Conclusion:** Agreement between IMSure and ion chamber is sufficiently good that IMSure may be useful as a first check of the treatment planning dosimetry, but care is needed in determining an appropriate action level. Ion chamber or similar QA measurements will still be needed.

SU-FF-T-223

Evaluation of Dosimetric Properties of 6 & 10 MV Photon Beams From a Liner Accelerator with No Flattening Filter

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Purpose: To study the dosimetric properties of an IMRT treatment beam after removing the flattening filter. Our goal is to show that more efficient IMRT treatments can be performed on a standard IMRT-capable linac after the flattening filter has been removed. **Method and Materials:** Measurements and Monte Carlo simulations were performed of 6 and 10 MV photon beams from an Elekta SL-25. Comparisons of the properties of these beams were made, with and without the flattening filter. %dd curves, beam profiles and photon fluence spectra were the primary method of comparing the beams. A study using the LATCH option in BEAMnrc was also performed to determine the original of scattered photons that contribute to the dose outside of the treatment field. **Results:** Dose outside the treatment field was found to be reduced by up to 5.8%, depending on the field size. Photon fluence on the central axis of the 6 and 10 MV beams increased by a factor of 2.35 and 4.18. **Conclusion:** Our Monte Carlo study showed that by removing the flattening filter the amount of laterally scattered photons from the jaws and MLC's was reduced leading to lower photon fluencies outside of the treatment field. It is hypothesized that inverse treatments plans created using these filter-free beams would lead to a higher degree of conformation of the dose to the target. The increase in photon fluence that is induced by removal of the flattening filter is predicted to lead to shorter treatment times.

SU-FF-T-224

Evaluation of First Macro Monte Carlo Based Commercial Dose Calculation Module for Electron Beam Treatment Planning and New Issues for Clinical Consideration

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Purpose: To present our experience of commissioning, testing and use of the first commercial Macro Monte Carlo based dose calculation algorithm for electron beam treatment planning. To investigate new issues regarding dose reporting (dose-to-water vs. dose-to-medium) as well as statistical uncertainties for the calculations arising when Monte Carlo based systems are used in patient dose calculations. **Method and Materials:** Phantom images studied were obtained through a CT scanner and DICOM image transfer. The calculated dose distributions and monitor units were validated against measurements with film and ionization chambers in phantoms containing 2D and 3D type low and high density inhomogeneities at different source-to-surface distances. The investigated electron beam energies ranged from 6 to 18 MeV. **Results:** Newly required input data for a Monte Carlo based electron beam commissioning are presented. The result of validation shows an excellent agreement between calculated and measured dose distributions in all tested cases . The calculated monitor units were within 2% of measured values except for 6 MeV beam and small cutout fields at extended SSDs (>110 cm). The investigation on the new issues of dose reporting demonstrates the differences up to 4% for lung and 12% for bone when "dose-to-medium" is calculated and reported instead of "dose-to-water" as done in conventional treatment planning systems. **Conclusion:** The accuracy of the Monte Carlo calculations is shown to be clinically acceptable even for very complex 3D-type inhomogeneities. As Monte Carlo based treatment planning systems begin to enter clinical practice, new issues, such as dose reporting and statistical variations, may be clinically significant. Therefore it is imperative that a consistent

approach to dose reporting is used. **Conflict of Interest:** Research sponsored by Varian Medical Systems.

SU-FF-T-225

Evaluation of Optically Stimulated Luminescence (OSL) Dosimetry for High-Energy Photon and Electron Beam Measurements in Radiotherapy

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Purpose: The precision and accuracy of the Optically Stimulated Luminescence (OSL) for determination of absorbed doses delivered by photon and electron beams from linear accelerator was investigated. The dependence of the OSL dose measurements with variations in temperature, field size, dose rate, and energy of the beam was also investigated. This study complements previous investigation on 6MV photons which showed that the OSL technique can provide dose estimates with a precision of 0.7% for a single measurement (1 dosimeter). **Method and Materials:** OSL doses were obtained for various depths in a water phantom for photons (6 and 18 MV) and electrons (6 to 20 MeV) and compared to data obtained from ionization chamber. Al_2O_3:C OSL dosimeters (7mm diameter by 0.3mm thickness) were irradiated using a linear accelerator (Varian 21 EX S/N 2833) at SSD = 100 cm. The OSL measurements were carried out using a Risø TL/OSL-DA-15 reader with green light stimulation and using a readout procedure that eliminates dependences on the mass or sensitivity of the dosimeter. **Results**: Depth-dose profile for 6 MV photon showed a high precision (0.5%) and accuracy, the difference between the OSL dose and the ionization chamber data being smaller than ±1.1% in all cases. The OSL measurements appear to be independent from variations in temperature, field size, and dose rate, with differences smaller than 1% compared to ionization chamber data for the 6MV photon beam. The data for the 18 MV photon beam and the electron beams are still being analyzed and will be presented. **Conclusion**: The results demonstrate that the OSL of Al_2O_3:C (dosimeters) provides reliable high-precision and accurate dose estimates, with no dependence on temperature, field size, or dose rate. The OSL technique with automated readers offers a simple and effortless method, since no precise control of mass of dosimeter is required.

SU-FF-T-226

Evaluation of Radiation Therapy Treatment Plans Through Conventional IMRT and Inversely Planned Intensity Modulated ARC Therapy (IMAT), A Clinical Comparison

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Purpose: The goals of this study were to evaluate the difference in target dose uniformity and dose distribution through mean DVH and OAR analysis for a given PTV. Dosimetric analysis were also extended to compare sparing of normal tissue and critical structures between two treatment planning techniques. **Methods and Material:** The ADAC Pinnacle inverse planning system was used to generate conventional IMRT inverse plans for a few head & neck patients. These plans were then compared with treatment plans generated using the IMAT software package manufactured by 3D line USA Medical System Corp. Using axial CT for the same patients, targets, and numerous critical structures were delineated and "best" plans were developed in each environment. In IMAT planning, continuous and dynamically shaped arcs were planned through aperture optimization and leaf sequencing. The dose delivery was accomplished through a specially designed MICRO DMLC with 3 mm leaf width and double focus focalization. **Results:** For IMRT plans, 5 or 7 co-planar arcs were used and treatment plans were generally optimized using a pre-defined set of dose objectives, penalties, min and max dose and percentage of volume required. The IMAT plans were designed with typically two co-planar arcs of 180 degrees around the patient with similar dosimetry objective parameters. The percentage coverage for V95 in targets 1&2 were 94.9 ± 2.8 and 95.1 ± 2.1 for IMRT and 98.4 ± 2.6 & 98.1 ± 2.8 for IMAT respectively. Sparing of critical structures was generally better in IMAT, a detail of which will be presented at the meeting. **Conclusions:** In the IMAT technique with direct aperture optimization, dose distribution within the target was found to be better by 8%. Superior critical structure sparing was achieved as compared with similar plan using IMRT technique. The IMAT technique may be considered as an alternative to tomotherapy.

SU-FF-T-227

Evaluation of Six Dosimetric Indices for Cyber Knife Stereotactic Radiosurgery Treatment Planning

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Purpose: To evaluate effectiveness of using six dosimetric indices in evaluating Cyber Knife SRS treatment plans. To investigate the dependence of these indices on the target volume and the histology of the treated tumor. To examine the effect of treating large volume lesions on the dosimetric properties of a treatment plan. **Method and Materials:** 154 treatment plans for Cyber Knife SRS of acoustic neuroma (AN), melanoma, meningioma, NSCLC and pituitary adenomas (PAs) were analyzed using six dosimetric indices: prescription isodose line PI, tumor isodose and volume coverage indices TI_{100} and TV_{100}, homogeneity index HI, conformality index CI and a modified CI (mCI). These indices and their averages for each tumor type were examined for dependence on the size of the treated tumor and its histology. **Results:** TV_{100}, PI and TI_{100} showed a decrease with tumor size, HI showed a slight increase with tumor size, while CI and mCI showed little dependence on the tumor size. CI for all five treated tumor types was closely clustered about 1.44, while HI showed greater dispersion for melanomas and NSCLC, but closer clustering about 1.39 for PAs, meningiomas and ANs. **Conclusion:** AN and melanoma plans showed the best on average tumor coverage while NSCLC showed the worst. Modified CI and CI indices were the lowest for the ANs and meningiomas, while HI performance was the best for ANs, intermediate for melanomas and PAs, and the worst for NSCLC. Modified CI showed very little dependence on the tumor size. PI and TV_{100} showed a trend towards rapid decrease with tumor size and therefore less coverage beyond 10 cc volumes for melanoma, meningioma and PA and beyond 100 cc for NSCLC. All six indices were found to be a useful tool for routine use in evaluating stereotactic treatment plans at our institution.

SU-FF-T-228

Evaluation of Surface and Superficial Dose for Head and Neck Treatments Using Conventional Or Intensity-Modulated Techniques

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With increased use of intensity-modulated radiation therapy (IMRT) techniques questions have arisen as to selection of an optimum treatment approach when either superficial sparing or treatment is desired. Other work has pointed out the increased skin dose resulting when multiple tangential beams are applied to head and neck treatment, as is the general case in IMRT planning. Helical tomotherapy might be expected to result in even further enhanced skin dose compared with conventional bilateral field treatment. We have designed a typical nasopharyngeal target volume in an anthropomorphic head and neck phantom. Three different treatment techniques have been used to optimally treat this target, including bilateral static fields, a standard 8 field IMRT approach and helical tomotherapy. The phantom was immobilized in a standard treatment position and treated on a Varian 2300cd linear accelerator and on a Hi-Art Helical tomotherapy unit. Thermoluminescent dosimeters (LiF) were placed on the surface of the phantom at a number of test positions. Kodak EDR2 films were also sandwiched between three of the phantom sections in the treated volume. Measured doses at the surface and as a function of depth are compared with the planning system predictions for each treatment technique. Preliminary surface dose measurements indicate 10-15% higher lateral surface doses and 20-30% higher anterior doses for both IMRT and tomotherapy, as compared with bilateral treatment, but lower intermediate doses 5cm anterior to the lateral CA for both IMRT techniques. The tomotherapy planning system appears to overestimate surface doses while Eclipse appears to better estimate these doses.

SU-FF-T-229

Evaluation of the Accuracy of the Electron Monte Carlo Algorithm in Eclipse Treatment Planning System

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Purpose: To evaluate the accuracy of Varian electron Monte Carlo (eMC) dose calculation algorithm after commissioning in Eclipse by comparing the output factors, profiles and PDDs generated from the algorithm to those measured in water. **Method and Materials:** A synthetic CT data set of a flat-water phantom was created in Eclipse Treatment Planning System. Dose distributions in the water phantom were generated with the eMC algorithm for multiple field sizes, with open and custom inserts, for multiple energies, and at 100cm and 110cm SSD. The algorithm parameters were 1% accuracy, medium 3-D Gaussian smoothing method and calculation grid sizes of 1-2mm. In water measurement of profiles and PDDs were performed with a Wellhofer scanning tank system. Output factors were measured as the ratio of output relative to the calibration condition. **Results:** For output factor comparisons, the mean difference is 0.2% for 100cm SSD and 1.6% for 110cm SSD, and the standard deviation is 0.6% and 0.7% respectively. The plot of PDDs from eMC plans overlaid with those of the measurements show good agreements except for the first 1 to 2 mm on the surface. eMC plans display surface dose by interpolating the dose at the first grid point inside the phantom and the first grid point outside the phantom, resulting in the surface underdose. Profile plot comparisons show good agreements for FWHM (difference <2mm) and for dose in the plateau region. For large cone sizes of 20x20 and 25x25, eMC profiles exhibit a flatter plateau region versus the round shoulders observed in the profiles measured in water. **Conclusions:** Our evaluation demonstrated that the eMC algorithm performs well in a homogeneous water phantom with both open and custom inserts and at both standard and extended SSD.

SU-FF-T-230

Evaluation of the Performance of An Optical CT Scanner

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Purpose: Optical CT technology has received much attention recently in the areas of 3D gel dosimetry and biological imaging, owing to its uniqueness in offering high contrast 3D images for optically transparent objects. In this work we evaluate the performance of a commercial optical CT scanner OCTOPUS™ to ensure its imaging qualities. **Method and Materials:** The output stability of the He-Ne laser in the scanner was measured for 10 hours. The ratio of the output over a reference measurement of the laser beam was monitored as well. The linearity response of the detector (photodiode) was evaluated by measuring the transmission light through the films that have known transmittances of 85.1%, 42.7%, 30.2%, 20.9%, and 3.9%. A thin wire of diameter 0.2mm was used for imaging to estimate imaging resolution. Multiple of such wires embedded in a gel at different locations were scanned to evaluate the geometric accuracy of imaging. A uniform gel slice was used to analyze imaging uniformity. The imaging linearity of the scanner was evaluated by scanning a gel slice containing a few optical contrast inserts. **Results:** The output of the laser shows a 4% variation in the 10 hours measurements but the effect of such variation was greatly reduced to 1% by normalizing the output measurement to the reference measurement of the laser signal. The photodiode shows a linear response within 1%. The imaging resolution of 1mm, uniformity of 1%, geometric accuracy within 1mm, and linearity of 1% can be achieved by the optical CT scanner. **Conclusion:** The evaluation demonstrates that the optical CT scanner has the capability of imaging 3D optical objects with high resolution and accuracy. The application of high quality optical CT in gel dosimetry and tumor tissue imaging would provide better understanding of 3D dose distributions and 3D biological structures and functions.

SU-FF-T-231

Evaluation of the Spatial and Dose Resolution of a New 3D Polyurethane Dosimeter

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Purpose: To determine the dose resolution and spatial stability of PRESAGE™, a new three-dimensional (3D) polyurethane dosimeter. Methods and Materials: PRESAGE™ dosimeters were irradiated to doses between 0.5 Gy and 10 Gy using stereotactic beams to develop a dose response curve and determine the dose resolution. A PRESAGE™ dosimeter was also placed in a water tank with the top surface coincident with the water surface and irradiated using a half-blocked field delivered by a linear accelerator to investigate the spatial integrity of the dose distribution. An additional PRESAGE™ was irradiated in a similar fashion; however the total dose was delivered in 3 fractions given over 3 days in order to investigate the affect of fractionation on spatial stability. All dosimeters were scanned using an OCT-OPUS™ laser CT scanner. **Results:** The PRESAGE™ dosimeter showed a monotonic and easily characterized response with dose. The dose resolution, determined at the 95% confidence level, was found to be comparable to polymer gel formulations. The width of the measured penumbra was 3.98 mm when irradiated in a single fraction and 4.23 mm when irradiated in multiple fractions. Neither dosimeter demonstrated a dose overshoot near the steep dose gradient. **Conclusions:** This work demonstrated the potential for PRESAGE™ to be used for 3D dosimetry. The dose distributions were found to be spatially stable in high-dose gradient regions. Also, the dosimeter did not exhibit the dose overshoot often observed with polymer gel dosimeters. Further work is required to optimize the dose resolution of the dosimeter. The investigation was supported by PHS grants CA 10953 awarded by the NCI, DHHS.

SU-FF-T-232

Evaluation of the Volumetric Coverage for Head and Neck Carcinoma Using the Traditional 3D Versus IMRT RTOG Modified Dose Schema

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Purpose: To evaluate the volumetric coverage of Head and Neck patients planned using the 3D technique of 7040cGy/38fx dose schema versus modified IMRT RTOG 0022 multi-tier dose schema with (High Risk) HR PTV 6784cGy/32fx; (Intermediate Risk) IR PTV 5760cGy/32fx and (Low Risk) LR PTV 5440cGy/32fx. We evaluated 4 patients whose diagnoses were Oropharynx, Supraglottis and 2 Base of Tongue carcinomas. **Materials and Methods:** Treatment plans using traditional 3D planning technique and Inverse Planning IMRT were developed using CMS XiO treatment planning system. The same targets and critical structures were used for both dose schema. The dosimetric plans were compared with respect to dose conformability and dose to the critical structures, using dose volume histograms to evaluate volumetric coverage. **Results:** Our Modified IMRT RTOG plans showed more conformal isodoses and provided better coverage around the various PTV than the traditional 3D. Also the Dose Volume Histogram evaluation showed better sparing of organ of risk especially the Parotids with the IMRT plans.**Conclusion:** The Modified IMRT RTOG dose schema gave a better volumetric target coverage, better organ at risk sparing, better biological effect with 32fx versus 38fx, more skin sparing, less parotid dose, but required stringent immobilization criteria. The treatment is completed solely with photon fields and there is no need for field matching of photon and electron as with the traditional 3D. Further studies are needed to establish the true clinical advantage of this multi-tier dose schema.

SU-FF-T-233

Example Responses of the Free Radical Diagnostic Alpha-Diphenyl-Piorhylhydrasy (DPPH) to a Conventional Dose Rate and a Very High Dose Rate Electron Beam

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Alpha-Diphenyl-piorhylhydrasy, or DPPH, a free radical diagnostic, can be used as a dosimeter when it is suspended in a medium that is at least partially translucent. The amount of color change of DPPH from a nominal purple to yellow is an indication of the number of free radicals created.

Purpose: As a preliminary investigation, we examined two different combinations of DPPH and the response to two different 6 MeV electron beams. **Method and Materials:** The combinations consisted of DPPH with water and with bovine serum albumen, (BSA). The two electron beams were from a Varian 2100EX with a conventional dose rate, and from a modified Varian Saturne SL42 with a very high dose rate. The Saturne

was operated in 6 MV photon mode with its target and monitor chambers removed so the dose rate of the electron beam was over 3000 times higher than the conventional dose rate. The peak instantaneous dose rate, which occurs when an "electron bunch" impinges, is over 10^7 Gy/min for the SL42. Approximately 2 ml of the DPPH combinations were irradiated in 3 cm diameter culture dishes to different doses. Controls were taken and exposed to the same environmental conditions as the irradiated dishes. Rapid color change occurred within seconds of irradiation, and the color change was analyzed on a Power Wave X Bio-Tek analyzer. **Results/Conclusions:** Although there is more scatter in the preliminary data for the SL42 irradiation, the response from both beams can be approximated as being linear up to the maximum dose measured, 6000 cGy. The slope of the response for both beams is about the same, which indicates that the free radical activity is not heavily influenced by the dose rate within this range. The possibilities of using DPPH as a "biological" dosimeter will be discussed.

SU-FF-T-234

Expected Diode Readings for In-Vivo Dosimetry in Electron Beams

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Purpose: To develop a practical method for calculating expected diode readings for in-vivo dosimetry in electron beams. **Methods and Materials:** Electron beams of 6, 8, 10, 12, and 15 MeV from an Elekta SL 25 series linac, using 100 and 110 cm SSD, were investigated. Several circular cut-outs with diameter ranging from 2.3 to 6.0 cm were constructed for the 6x6 cm² cone and from 4.1 to 8.5 cm for the 10x10 cm² cone. Cut-out factors were measured for each energy and SSD, using an ion chamber placed at dmax. Similar measurements were also made using a previously calibrated diode placed on the surface of the phantom. A diode cut-out factor was obtained from these measurements. For each cone and SSD, graphs of cut-out factors and of diode cut-out factors vs. cut-out diameter were constructed. The points were connected by a smooth line, such that we could relate the cut-out factors as a function of the cut-out diameter, and the results were compiled in the form of tables for ease of use. Output factors were measured for all available cones, all energies, and different SSDs using the ion chamber. Corresponding diode output factors were also measured, and tables of output factors and diode output factors were constructed. The following formula was used to calculate expected diode readings when using electron beams:

$$DiodeRdg = \frac{Dose * Diode\,Output\,Factor * Diode\,Cut-Out\,Factor}{Output\,Factor * Cut-Out\,Factor}$$

Results: The method was validated by calculating expected diode readings for several different doses, cut-outs, energies, and SSDs, and comparing to measured values. Agreement between calculated and measured readings was better than 1.3%. **Conclusions:** This work presents a practical method to calculate expected diode readings for electron beams, based on a few measurements performed with electron cut-outs of different diameters, and the presentation of the results in the form of tables.

SU-FF-T-235

Experimental Evaluation of a MOSFET Dosimeter for Therapeutic Proton Beams

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Purpose: Metal oxide-silicon semiconductor field effect transistor (MOSFET) dosimeter has been widely studied to use a dosimeter for patient dose verification. The major advantage of this detector is its size, which acts as a point dosimeter and also its ease of use. Here, the MOSFET dosimeter has not ever used for proton dosimetry. Of course, it is important for proton radiotherapy to evaluate proton dose distributions accurately in the body. Therefore, in order to measure proton dose distributions in heterogeneities and small fields, we used a MOSFET dosimeter for the first time in proton dosimetry. In this study, we evaluated the characterization of the MOSFET dosimetry for therapeutic proton beams. **Method and Materials:** A commercially available TN502RD MOSFET System (Thomson & Nielsen, Canada) was used in the study. Proton beams with 190 MeV were irradiated at National Cancer Center East in Japan. We evaluated dose reproducibility, linearity and fading effect at high sensitivity bias. Then, depth dose distributions for mono-energetic and spread-out Bragg peak proton beams were measured using the MOSFET dosimetry. All measurements were performed in solid phantom. **Results:** The MOSFET was characterized for dose reproducibility, linearity and fading effect. The dose reproducibility was ± 2.0%. The MOSFET response was linear with dose within ±1.0 mV. We observed fading effect of about 2.0% in 15 minutes. In depth-dose measurements, the MOSFET response depended strongly on proton energy. Bragg peak obtained by the MOSFET were estimated to be about 40 % lower than those of ionization chamber. **Conclusion:** We found that the MOSFET has stopping power dependence for proton beams. It is hard for clinical application to use the MOSFET dosimeter. We need to improve proton energy dependence for the MOSFET dosimeter

SU-FF-T-236

Experimental Validation of the Inner Shell Ionisation Model to Predict the Radiosensitisation Induced by the IDU and BrDU Halogenated Pyrimidine

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Purpose - Halogenated pyrimidines (IDU and BrDU) are heavy atoms compounds used as radiosensitizers. For IUdR, it has been questionned if inner shell ionisations (ISI) and Auger cascades that are rare events using megavoltage beams could be at the origin of the radiosensitization. The purpose of this work is to validate experimentally the ISI model previously published by the authors. This model involves the photon spectrum degradation in the tissues and the ISI induced by secondary electron knock-on. **Material and Methods** - The ISI model predicts that the primary photon energy, irradiation depth, and type of halogen influence the Sensitization Enhancement Ratio (SER). Radiobiological assay were used to evaluate cell survival of the radioresistant CHO cell line using ^{192}Ir or ^{60}Co irradiation at various depths in water phantoms (2, 5 and 10 cm). Cells were grown in exponential or in plateau phase to account for different ratios, and exposed 3 days before irradiation to 4 mol of IDU or BrDU. The experimental validation of the ISI model was realized by testing for each experimental condition the correlation between i/- the theoretical SER calculated using Monte Carlo simulation of the overdosage due to Auger cascades; and ii/- the SER calculated from the radiobiological assays. **Results: –** The experimental SER values are in the same range than the theoretical one, and they are significantly correlated (p=0.017). As predicted by the ISI model, there is an influence of depth and energy that is stronger for the IDU than the BrDU. Also, as predicted by the model, the largest SER is found using IDU and ^{192}Ir. **Conclusions –** The ISI model is robust in predicting the radiosensitisation for a given experimental situation. Based on a pure particle-matter interaction modelisation, the ISI model could be extended to other particles type, including electrons, protons of heavy ions.

SU-FF-T-237

Exposure Rate Calculation: Effect Of Photon Divergence Near A Radioactive Source

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The objective is to show that near a radioactive source the commonly used exposure rate equation has to be modified in order to take photon divergence into consideration. This is accomplished by showing the derivation of the standard equation in detail and then illustrating where photon divergence needs special consideration. The commonly used equation for calculating the exposure rate is Eq.1 and the modified equation Eq.2. The reason for the modification is that the irradiated volume per unit entrance area is larger at close proximities. This means that charge produced per unit volume per photon penetrating the entrance area is smaller at close proximities than at a distance. Since the exposure is defined as charge liberated per unit volume or unit mass of air this results in Eq.1 overestimating the exposure rate. This is of relevance (a deviation of 10% or more between expected and measured value) at distance smaller than 5 cm. At larger distances the difference between both equations becomes negligible. An experiment using a Tc-99m point source and a calibrated exposure rate meter is performed to compare theoretical and experimental values and to show the difference between the predictions of the two equations. This comparison showed very good agreement of the measured values and the predicted values based on Eq.2 and an overestimation of the exposure rate calculated using Eq.1. This has also

implications for the tabulation of Gamma factors ( ) and their units: (mR•cm^2)/(mCi•hr) vs. (mR•cm^3)/(mCi•hr).

$$Eq.1: \dot{X}\left[\frac{mR}{hr}\right] = \Gamma \frac{Activity}{dis\tan ce^2} \quad Eq.2: \dot{X}\left[\frac{mR}{hr}\right] = \Gamma \frac{3\,Activity}{(dis\tan ce+1)^3 - dis\tan ce^3}$$

SU-FF-T-239

Extracapsular Radiation Dose Annulus Correlates with Biochemical Control in Low-Risk Brachytherapy Patients: Results of a Prospective Randomized Trial

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Purpose: Recent studies have suggested that extracapsular permanent prostate brachytherapy treatment margins correlate with biochemical control. It is likely that volumetric dosimetric parameters will be more robust than selected radial measurements. We evaluated the impact of extracapsular volumetric dosimetric parameters on biochemical control in low-risk patients. **Materials and Methods:** 263 consecutive low-risk prostate cancer patients randomized to Pd-103 versus I-125 were implanted with a brachytherapy target volume consisting of the prostate with a 5 mm periprostatic margin. The median follow-up was 4.2 years. All patients were implanted at least 3 years prior to analysis. Within 2 hours of implantation, an axial CT was obtained for post-implant dosimetry. A 5 mm 3-dimensional periprostatic annulus was constructed around the prostate gland and evaluated in its entirety and in 90° segments. Dosimetric parameters for the prostate gland and the annulus consisted of V100/150/200 and D90. Biochemical progression-free survival was defined by a PSA ≤ 0.5 ng/mL. **Results:** Mean postoperative dosimetry was significantly different (p < 0.001) between I-125 versus Pd-103, respectively, for V100 of 97% versus 93% and D90 of 122% versus 112%. Annulus dosimetry was significant (p < 0.001) for a V100 of 80% versus 70% and a D90 of 91% versus 85% for I-125 versus Pd-103, respectively. Six-year biochemical progression-free survival was 99.6% versus 99.2% for I-125 versus Pd-103 (p = 0.125). The most recent median post-treatment PSA was 0.1 ng/mL and < 0.04 ng/mL for I-125 and Pd-103. Biochemically disease-free patients had statistically higher prostate and annular dosimetric values. In Cox regression analysis, variants of annulus dosimetry were the best predictors for biochemical control in the I-125, Pd-103, and overall cohorts. **Conclusions:** A postimplant 5 mm 3-dimensional periprostatic annulus provides substantial information regarding dosimetric coverage and appears to be an important predictor for biochemical outcome in low-risk patients.

SU-FF-T-240

Fast Efficient Global Fluence Map Optimization Using a Parallelized Objective Function for IMRT Treatment Planning

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Purpose: Adaptive intensity modulated radiation therapy (IMRT) with image guidance requires frequent re-optimization of the dose distribution for treatment plan verification. We present an efficient and robust algorithm that solves fluence map optimizations (FMO) for IMRT and provides good target coverage of homogeneous targets ($R_{95\%} \geq R_{Rx}$), while at the same time maintaining dose to critical structures within specified tolerances. **Method and Materials:** An analytic non-linear convex model was developed that uses a projected gradient algorithm with Armijo line search to solve fluence map optimizations for IMRT treatment planning. Voxel based penalty functions and a fluence non-negativity constraint were applied for the iterative minimization of a parallelized convex objective function on a dual node processor. Model parameters were tuned for three treatment sites (H&N, CNS, and prostate) and results assessed in-terms of algorithm speed, fluence maps and dose volume histograms. All cases were investigated for 5, 7, 9, and 11 equidistant beam angles and a generic set of parameters that provide good results obtained for each site. Improvements in plan quality are achieved on a case-by-case basis through dynamic parameter weighting. **Results:** Our implemented projected gradient algorithm model solved FMO's, on a dual node processor, for the three sites in 0.34-8.55 seconds corresponding to 10-75 iterations. Dynamic weighting produced tighter target coverage, while still maintaining critical organs within acceptable tolerances with only a small increase in FMO calculation times. **Conclusion:** The FMO optimization algorithm described shows that voxel based fluence map optimizations are feasible down to <10 second time scales while still achieving good target coverage and critical structure sparing for IMRT treatment verification and planning. A Further 25% improvement in FMO calculation time is expected using up to 6 node parallelization. **This work supported in part by NSF grant DMI-0457394 and the State of Florida DOH Grant 04-NIR03**

SU-FF-T-241

Feasibility and Accuracy of Using Cone-Beam Computed Tomography (CBCT) Scans for Stereotactic Radiosurgery (SRS) Planning and Dose Verification

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Purpose: To evaluate the feasibility and accuracy of using on-board imager (OBI) cone-beam computed tomography (CBCT) scans for stereotactic radiosurgery (SRS) planning and dose verification. **Method and Materials:** The simulation CT scan and OBI CBCT scan of a Rando head phantom were imported into a commercial SRS treatment planning system, BRW-coordinate localized and co-registered. A simulated clinical target volume (CTV), planning target volume (PTV) and critical organs were contoured on the simulation CT scan and transferred to the CBCT scan. A SRS treatment plan with 10 static conformal fields was created using the simulation CT volume. Beam parameters of this CT plan were also imported into a second treatment plan using the CBCT volume. Dose volume histogram (DVH), mean dose, monitor unit (MU), and equivalent depth of the CBCT plan were compared with those of the CT plan, with and without the inhomogeneity correction. **Results:** The DVH of CTV, PTV and critical organs for these two plans were indistinguishable without inhomogeneity correction. The MU and equivalent depth of the CBCT plan were on average 0.2 % (standard deviation (SD)=0.4%) higher and 0.3% (SD=1.3%) lower, respectively, than the CT plan. Although the DVH of these two plans were comparable with inhomogeneity correction, significant discrepancy was observed for the MU (mean=1.4% and SD=1.3%) and equivalent depth (mean=5.3% and SD=3.9%) due to the lower Hounsfield numbers of the CBCT scan. However, when the CT plan was applied to the CBCT volume, mean doses to PTV and critical organs were only slightly (1.2% and on average 1.0% with SD=3.2%, respectively) higher than those of the CT plan. **Conclusion:** The OBI CBCT scans can be used for SRS planning and dose verification. More accurate Hounsfield number calibration is needed for inhomogeneity correction.

SU-FF-T-242

Feasibility of Using a 2D Diode Array System for Clinical Electron Beam Measurements

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Purpose: To investigate the feasibility of using a 2D diode array system for clinical electron beam measurements **Method and Materials:** Dose distributions were measured for electron beams (EBs) generated on an Elekta Synergy LINAC (Elekta Ltd., UK). Beam data were measured using the Blue Phantom and converted on OmniPro-Accept (Scanditronix Wellhöfer, Bartlett, TN) according to AAPM TG 51. These data were used to commission Eclipse TPS (Varian, Mountain View, CA). MapCheck Model 1175 (Sun Nuclear, Melbourne, FL), a 2D diode array system, was exposed using largest applicator size 20cm×20cm at SSD 123.5cm for array calibration. Central axis dose was also calibrated. Plans were generated and measured by MapCheck for several different geometries. Exported plans were compared with measured dose map using comparison criteria of ±3% difference and ±3mm distance-to-agreement (DTA) within 10% isodose-line threshold. Set-ups include different cone sizes (field sizes) and energies at different SSD's, irregular surface, and different depths. Direct comparisons between MapCheck and ion chamber results were also performed. **Results:** Output factors measured with MapCheck and ion chamber agree within 1.3%. Comparison of measured and planned electron beam dose maps for 9MeV EB with 14cm×14cm applicator, SSD=100cm, depth=2cm showed 99.7% passing rate for stated criteria. Central axis dose differed by 1.6%. Passing rates and central axis dose differences for two electron applicators (10×10 and 14×14) at different SSD's (95.4, 100, and 104.4) were also summarized. Overall, >90% passing rates and <3% central axis dose differences can be achieved. Most of the failed points are at the edge. A stepped phantom was also tested and is under further

investigation. **Conclusions:** Preliminary results show that MapCheck can be used to perform quick and relatively accurate electron beam dose map comparison. It may also prove useful for electron beam intensity-modulated radiotherapy (EB-IMRT) measurements in the future.

SU-FF-T-243

Feasibility of Using Stereotactic Body Radiation as An Alternative to HDR for the Treatment of GYN Sites

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Purpose: Brachytherapy is frequently used to boost volumes at risk in the treatment of gynecological tumors. Not all the centers have an HDR, or LDR capabilities, however, all have a linear accelerator. We evaluated the possibility of using external beam radiation therapy using Stereotactic Body Radiation Therapy (SBRT) or Intensity Modulated SBRT (IM-SBRT) approach. **Method and Materials:** Volumes covered by the HDR prescription were used to define a CTV, with a prescription of 3250 cGy to the CTV over 5 fractions. Planning started with 36 equi-spaced non-coplanar beams and beam weight optimization was used to choose the most effective beam orientations. Then, unmodulated beams produced the SBRT plans and by allowing beam modulation IM-SBRT plans were generated. Both absolute and film dosimetry were performed to ensure accurate deliverability. **Results:** At least 96% of the CTV was covered by the prescription dose for SBRT and IM-SBRT plans. Relative to the original HDR plan, bladder dose reduced by 12.8% and 38.5% by SBRT and IM-SBRT respectively. Rectal dose increased by 49.3% using SBRT and decreased by 5.1% using IM-SBRT. As expected, The integral dose outside CTV was higher in SBRT and IM-SBRT approaches. **Conclusion:** SBRT and IM-SBRT methods provided similar tumor coverage to HDR. IM-SBRT reduced dose to bladder and rectal point. In the near future we will be evaluating a novel new device to localize the anatomy on a daily basis so that a precise delivery is possible.

SU-FF-T-244

Feasibility Study Into Glass Rod Detectors as a "Postal Dosimeter"

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Purpose: To investigate the potential of glass rod detectors (GRDs) for a "dosimetry by mail" service and possible use by the Advanced Technology QA Consortium (ATC) for credentialing of institutions in multi-institutional clinical trials. Since thermoluminescent detectors (TLDs) are established for a number of mail-in calibration checks, specific niche areas were sought for GRDs. **Method and Materials:** Two areas of investigation that proved fruitful were Gamma Knife (Elekta AB, Sweden) for helmet output factors and absolute calibration and when confirming the calibration of a cell irradiator (Rad Source Technologies Inc, Fl. USA). One difficultly with the cell irradiator is that the door remains closed during beam on so that ion chamber, diode and MOSFET detector calibrations are problematic. GRDs were found to be particularly useful as they demonstrate insignificant energy dependence, no directional dependence and no significant dose rate dependence. **Results:** In collaboration with City University London, UK, specifics of alteration in GRD response to transatlantic shipment were studied. In particular energy response was studied using a variety of low energy X-ray spectra available at the National Physical Laboratory (NPL), Surrey, UK. A simple batch calibration process and assigning a small quantity of GRDs as controls were the only measures necessary when comparing mailed GRDs to those held in-house. This current work has demonstrated that the same level of accuracy as previously found by experienced users is possible by an "untrained" user, but it was noteworthy how explicit, simple and unambiguous instructions needed to be. **Conclusion:** GRDs represent a high accuracy dosimeter for a photon dosimetry "by mail" service that would cover energies from 20keV to 25MV and absolute dose values ranging from milli-gray to approximately 100 gray. GSD's appear to be well suited for use in anthromorphic phantoms for credentialing institutions for participation in multi-institutional clinical trials.

SU-FF-T-245

Feasibility Study of Focused and Non-Focused Photon MLC for Electron IMRT

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Introduction: Modulated electron radiation therapy (MERT) could be advantageous for some disease sites. Different modes of MERT have been investigated, such as optimization of energy for each entry angle, electron MLC, etc. Feasibility of using photon MLC for MERT is explored in this study. The depth doses, profiles, penumbra (90%-10%), lateral spread (10%-1%) and radiation leakage for energies 6-21 MeV and at various source-skin-distance (80, 90, 100 cm) are investigated. **Materials & Methods:** Using both a Varian (with non-focused MLC) and a Siemens (focused MLC) accelerators, beam characteristics at dmax are measured for possible beamlets from $1x1cm^2$ - $10x10\ cm^2$ for each electron energy at 80, 90 and 100 cm SSD. The profiles are collected using film dosimetry in solid water as well as ion chamber and electron diode measurements in a scanning water tank. **Results:** For both the focused and non-focus MLC, profiles obtained with 100 cm ssd exhibit a large penumbra (90-10%) in the range 4.2-7.5 cm for energies 6-21 MeV, the lower the energy, the larger the penumbra. At higher energies and 80-90 SSDs, the penumbra is much reduced. For example, for the focused MLC, it is 23 mm at dmax for 18 MeV, while for the non-focused MLC, it is 11 mm for the 20 MeV. The percent depth dose(PDD) curves though not as steep as that with an electron cone, are clearly more advantageous compared to a photon PDD with smaller exit dose. **Conclusions:** The key to MERT with existing photon MLC is to reduce the source-skin distance, while maintaining sufficient clearance for isocentric treatment. Our measurements indicate that beamlets <10x10, electron energies $\geq$ 12 MeV and SSD $\leq$ 90cm may provide clinical acceptable combinations for MERT with photon MLC. Focused and non-focused MLC differ slightly in the beam characteristics.

SU-FF-T-246

First Report On a Badge Survey for Family Members Living with Permanent Pd-103 Breast Seed Implant Patients

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Purpose: A phase I/II clinical trial is ongoing for a new form of accelerated partial breast irradiation using permanently implanted Pd-103 brachytherapy seeds. The procedure takes about one hour operating room time and the patient is released from the hospital the same day. One concerning issue associated with this procedure is the dose received by family members living with these implanted patients, particularly because the amount of overlying tissue in a permanent breast seed implant is much less compared to a permanent prostate seed implant. The purpose of this study is two-fold:1.) to determine measured doses to family members living with the implanted patients and 2.) to compare these measured doses with theory. The NCRP recommends a dose not exceeding 5mSv for family members living with implanted patients. Methods and Materials: Landauer luxel radiation badges (sensitive to 1mrem=0.01mSv) were given to family members living with implanted patients. Instructions were to wear the badge at all times when in vicinity of the patient for a period of 1-month. The raw badge readings (deep dose equivalent) were then extrapolated over the lifetime of the source to reflect total dose to the family member. A theoretical equation was developed (that accounts for the activity implanted, the seed type, the overlying tissue depth, and the time in vicinity of the patient) and this was compared with the measured badge readings. **Results:** To date, n=33 badge readings have been received. The average spousal dose was 0.94 mSv (n=21). The maximum and minimum doses were 3.1 and 0.01 mSv. The theoretical equation, in most cases, over-estimated the measured dose (up to a factor of 2.5). **Conclusions:** In all cases, the total dose received by family members was less than 5 mSv. The theoretical equation provides a worst case scenario estimate of dose to a family member.

SU-FF-T-247

FIRST, the First Choice in the Management of Localised Prostate Cancer?

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Purpose: To evaluate the clinical use of the FIRST system for the definitive treatment of localised prostate cancer. **Method and Materials:** From January 2003 through December 2005 a total of 634 patients were treated, either with the FIRST system (278) or with RAPID Strands (356). Patient characteristics were identical for both groups, but strands were more often used after TURP (19 vs. 3). We looked at implant data and side effects, also in relation to the use of loose spacers in the FIRST group. **Results:** Prostate volumes were similar (34 and 35.5 cc) as well as the number of seeds (mean 74 and 70). In total 20,526 Selectseeds and 24,866 stranded seeds were used. The number of loose spacers in the FIRST system was approximately the same as the number of active seeds. The number of seeds that disappeared from the body was the same (128 and 130), but migration within the body was higher with FIRST (48 vs. 0). Migration of spacers within the body cannot be detected. Toxicity according to the common toxicity criteria was similar for both techniques. Acute retention was found in 24 FIRST patients (8.6%) and 27 strand patients (7.5%). Infection was found in 3 patients in both groups. Erectile dysfunction was found in 32% after FIRST and 28% after strands, but not assessed in more than 50% of all patients. None of the patients died of prostate cancer; intercurrent death was encountered in 4 FIRST and 6 strand patients. **Conclusion:** We cannot favour one of the techniques. There is a higher incidence of migration with loose seeds as used in the FIRST system, but no detrimental effects were observed. The use of polylactide loose spacers in FIRST did not result in detectable adverse effects; neither did the polyglactin wires in the stranded patients.

SU-FF-T-248

For Small Field Radiosurgery Intermediate Energy Photons (800kV) Show Superior Dose Distributions Compared to Megavoltage Beams

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Purpose: Beam penumbra is significant when using stereotactic radiosurgery to treat small volumes with limited microscopic extensions. It is challenging to irradiate these lesions if a highly critical structure is in close contact with the target. Previous Monte Carlo simulation has demonstrated that using Intermediate Energy Photons (IEP, above orthovoltage and below megavoltage) dramatically reduces the radiological penumbra for small field size radiosurgery (2 x 2cm^2) when compared to a standard 6 MV beam. This study aims at evaluating the dosimetric benefit of IEP. **Methods:** A virtual IEP unit based on an 800 kV beam spectrum was described in the Pinnacle^3 TPS including an extended kernel library to the kilovoltage range. A head phantom with a 1cm diameter target volume situated in the middle of the brain and at 1mm from a critical structure was used to assess the dosimetric advantage of IEP compared to 6MV beam. An 11 beam non-coplanar arrangement was used to cover the GTV without margin and a dose of 1000cGy was prescribed. Cumulative DVHs were generated for both energies and for the target, the critical structure and the entire brain. Optimal dosing percentages were chosen for dose normalization to ensure comparable target coverage. **Results:** The 800 kV and 6MV beams were dosed to 92% and 78% isodose lines respectively. DVHs demonstrate that the volume of critical structure that received 40% of the given dose was 5.5 % versus 10 %, and the maximum dose received by the target was 110% and 127% for the 800 kV and 6MV beams respectively. The increase in integral dose to the brain for the 800 kV beam is negligible. **Conclusions:** An 800 kV beam shows improvements in dose distribution conformality, homogeneity, and critical structure sparing compared to a standard 6MV beam.

SU-FF-T-249

Fractionated Grid Therapy in Treating Cervical Cancers

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Purpose: To evaluate the potential therapeutic advantage of external beam grid therapy in treating cervical cancer in comparison of conventional open field radiotherapy. **Method and Materials:** A Monte Carlo technique was employed to calculate 2-dimensinal dose distribution of a commercially available grid, and the linear-quadratic (LQ) model was applied to study the therapeutic advantage of using grid therapy for treating cervical cancers. A list of cervical cancer cell lines with known LQ parameters were used to calculate the radiotherapy response. Acutely responding normal muscle with α/β value of 3.1 Gy was used to evaluate the outcomes of between the open and grid field irradiations. The normal muscle tissue with three different sensitivities was assumed according to their response to a 2Gy open field. The therapeutic ratio based on sparing normal cells has been defined and calculated. The treatment regimens with 2Gy per fraction and 5 to 20 fractions were used in the calculations. **Results:** The survival fractions of normal tissues as well as tumor cells in the open and grid field are calculated. An appreciable therapeutic advantage has been demonstrated. Therapeutic ratio up to 9.5 for radio-sensitive normal muscles was found. However, the radio-resistant muscle does not show apparent advantage benefiting from the grid therapy. The results of data analysis showed that the therapeutic outcome depends not only on the single value α/β, but also on the individual α and β values of both the tumor and normal tissue cells. **Conclusion:** Monte Carlo technique was proven to be able to provide the dosimetric characteristics for grid therapy. The grid therapy in this study was found to be advantageous for treating the acutely responding cervical tumors ($\alpha/\beta>6$), but not for slow responding ones ($\alpha/\beta\leq6$). The acutely responding tumors and radio-sensitive normal tissues are more suitable for using the grid therapy.

SU-FF-T-250

Geometric and Inhomogeneity Corrections of In Vivo Dosimetry

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Purpose: *In vivo* dosimetry, the important QA procedure suggested by the ESTRO, requires geometric and homogeneity symmetries. However, these criteria may not be satisfied in clinical measurements. The present study provides a solution for *in vivo* dosimetry under asymmetrical conditions **Materials and Methods:** Two asymmetrical conditions are considered. These are the asymmetry of tissue materials and densities and the asymmetry of anatomic structures. We used Styrofoam and commercial bone tissue to simulate, respectively, lung and bone tissues and to assess the effect of tissue asymmetry. To study the effect of geometrical asymmetry, we shifted the plastic water phantom several centimeters off axis. The entrance and exit doses were measured by diodes, and the central axis dose was thus derived. These results are compared to experimental data measured using the ionization chamber. **Results:** The effect of geometrical asymmetry is more important than that of tissue asymmetry. The dose perturbation is 2% if we insert 2 cm Styrofoam or bone on one side of the phantom. But this perturbation increases to 3-5% in the central axis dose if we shift the central axis of the plastic water phantom by 2 cm. However, these perturbations can be reduced to less than 1% after asymmetric corrections. **Conclusion:** The tissue asymmetry causes less dose perturbation compared to that of the geometry asymmetry. Both asymmetries can be corrected as demonstrated in the present study.

SU-FF-T-252

HDR Endorectal Brachytherapy: Quality Assurance

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Purpose: Fractionated high-dose rate endorectal brachytherapy has been developed in our institution as a pre-operative down-staging modality. Since the treatment is fractionated (26 Gy/4) it is essential to reproduce the treatment planning dose distribution on a daily basis. In this paper we present the Quality Assurance (QA) steps developed to ensure patient based daily dose reproducibility. Method **and Materials:** The applicator used has a cylindrical symmetry. In addition to the applicator auto-radiographs used for the catheter physical length determination, there are two additional steps that have to be performed in order to reproduce a treatment planning dose distribution on a daily basis. Another correction has to be performed on a daily basis for rotation of the catheter channels. For this purpose, we use uniquely coded “dummy” source inserts that show themselves on a daily radiograph. The applicator is rotated and radiograph repeated until perfect alignment is achieved. **Results:** Since the applicator might not be

placed to the same depth inside the rectal lumen, there is a shift along the catheter axis that has to be performed on a daily basis. The amount of shift is determined by comparison of a daily radiograph and treatment planning DRR. **Conclusions:** Reproduction of the treatment planning dose distribution on a daily basis is crucial for the success of the fractionated 3D based brachytherapy treatments. Due to the cylindrical symmetry, two types of adjustments are necessary: applicator rotation and dose distribution shift along the applicator axis.

SU-FF-T-253

Helical TomoTherapy for Radiosurgery: Plan Optimization and Delivery Considerations

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Purpose: To quantify the quality and deliverability of Helical Tomotherapy plans for small targets. Plan quality can be improved via auxiliary structures used to increase the dose gradient outside the target volume. **Method and Materials:** Plans were created for a 1.0 cm diameter target (PTV), with and without the use of: (i) a 1 cm thick annulus surrounding the PTV as a "region at risk"; (ii) "blocks" placed superiorly and inferiorly to the PTV, truncating the length of the helical delivery. The dosimetric effects of these modifiers were analyzed. The consequences of the blocks in terms of required gantry rotation rate as a function of helical pitch were analyzed. **Results:** Dose gradient as measured via the effective radii of the 50% and 100% dose volumes is significantly increased via the use of blocking structures. Dose conformity is also increased. Reducing total couch translation distance to less than the beam width causes a reduction in number of rotations contributing dose to a given point. A higher dose per rotation is thus required, possibly reducing gantry rotation speed below the minimum. Reducing pitch increases number of rotations, thus allowing higher dose per helical pass. For example, in this case a small pitch of 0.1 allows delivery of 20 Gy to the PTV boundary in two helical passes, with a beam delivery time of 5 minutes per pass. **Conclusion:** Helical Tomotherapy is able to produce high dose gradients outside the target volume, especially with a restriction on helix length. Doses typically given in single fraction radiosurgery are deliverable via one or more helical passes within a single session. Judicious choice of helical pitch prior to planning can save time in arriving at optimal delivery parameters. **Conflict of Interest:** Research sponsored by TomoTherapy Inc.

SU-FF-T-254

Helical Tomotherapy Radiosurgery Planning

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Purpose: To quantify the conformity and gradient of stereotactic radiosurgery (SRS) plans planned with helical tomotherapy, and to compare helical tomotherapy SRS plans with conventional linear accelerator (linac) SRS plans. Methods and Materials: Representative radiosurgery cases were selected from a database of patients treated with conventional linac radiosurgery techniques. Simple and complex radiosurgery planning scenarios were investigated. For each case, hypothetical helical tomotherapy IMRT radiosurgery plans were developed using a HiArt helical tomotherapy unit (Tomotherapy Inc., Madison, WI). The HiArt hypothetical plans were compared to the conventional linear accelerator radiosurgery plans based on dose conformity, dose gradient outside of the target volume, and on dose-volume histogram analysis of adjacent radiosensitive structures. **Results:** Helical tomotherapy could theoretically be used to deliver very conformal radiosurgery dose distributions for small (<10 cm^3) target volumes while maintain a steep dose gradient outside of the target volume. Helical tomotherapy plans were generated which exceeded the RTOG radiosurgery acceptability criteria (planning isodose to treatment volume ratio < 2.0, maximum dose to peripheral dose ratio < 2.0). Average dose gradients of about 5mm between the prescription and half-prescription isodose shells were readily attainable. In cases with adjacent radiosensitive structures, helical tomotherapy plans provided target coverage and radiosensitive structure sparing comparable to conventional linac SRS plans. Tomotherapy beam-on times were longer than that expected for conventional linac SRS treatment, but still feasible. **Conclusions:** Helical tomotherapy radiosurgery plans can compare well with conventional radiosurgery plans in terms of dose conformity and gradient, and in radiosensitive structure sparing. If target localization and treatment delivery issues are addressed, helical tomotherapy units should be capable of satisfactorily delivering radiosurgery treatments. **Conflict of Interest:** Two of the authors (KR, GO) are employed by Tomotherapy, Inc.

SU-FF-T-255

Hetergeneity Dose Calculation Accuracy in IMRT Using An Anthropomorphic Thorax Phantom

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Purpose: To evaluate the accuracy of heterogeneity dose calculation algorithms from two commercial IMRT treatment planning systems **Methods and Materials:** The Radiological Physics Center (RPC) anthropomorphic phantom was irradiated by 6MV photons on a Varian linear accelerator from treatment plans created on the Corvus and Pinnacle treatment planning systems (TPS). The phantom has with TLD located in the tumor, heart, and spinal-cord and radiochromic film in three anatomical planes intersecting the tumor center and extending into the lung. Comparisons were made between each TPS calculation and measurement. Routine clinical procedures were followed and patient IMRT QA was performed on a homogeneous water phantom. Ion-chamber measurements were compared to the calculated values and the calculated dose distributions were adjusted, accordingly. A re-calculation by Pinnacle was made based on the MLC sequence files and monitor unit settings generated by Corvus, and compared to measurement. The Pinnacle recalculation of the Corvus beam definitions was performed for the anthropomorphic phantom and the QA water phantom deliveries. Criteria for the comparisons were per TG-53. **Results:** The Pinnacle IMRT TPS predicted dose within 1% of the TLD value at the tumor center, while the Corvus IMRT TPS overestimated the dose by 5%. The radiochromic films show at least 96% of the region was in agreement at the ±5%/3mm criteria level when compared to the Pinnacle TPS regardless of which delivery parameters were used. The Corvus TPS predicted about 61% of the region met the criteria at a ±5%/3mm level. **Conclusion:** The Pinnacle IMRT superposition convolution dose calculation algorithm provided clinically acceptable results (±5%/3mm). The Corvus IMRT finite-size pencil beam based algorithm with 1-D correction overestimated the dose and failed to meet the ±5%/3mm criteria within a majority of the PTV and penumbra regions. This work was supported by PHS grant CA10953 and CA081647 awarded by NCI.

SU-FF-T-256

High Dose Rate (HDR) Brachytherapy with Surface Applicators - Treatment for Nonmelanomatous Skin Cancer

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Purpose: To assess the use of HDR surface applicators as an alternative radiotherapy modality to external radiation for the treatment of skin lesions. **Materials and Methods:** A total of 17 patients were treated to 18 sites, which included lesions of the face, scalp, trunk and extremities. Thermoplastic casts were fitted with Leipzig Surface Applicators and custom molded to the patient for non-melanomatous carcinomas ≤ 2cm in diameter. A custom surface mold applicator (Freiburg Flap) was used for lesions up to 4cm. PTV included the tumor plus a 5mm margin. Photographs of the treatment volume were taken for monitoring of reactions. Prescribed dose was 5Gy/fraction, twice per week for four weeks to a 5mm depth. TLD's were placed at the center of the treated volume under the applicator and at critical structures (i.e. lateral canthus) twice during the course of treatment. **Results:** Patients' setup and reproducibility were accurate and treatment time was short. With the HDR surface applicators, dose distribution was uniform at the skin surface and at 5mm depth in the whole area of the applicator. Differences between the areas of maximum and minimum dose at this depth did not reach values higher than 5% of the prescribed dose. At the edges of the applicators, the dose gradient was sharp, with the detected dose at 5mm from the applicator negligible. An exudative radiation reaction was noted in some patients, which reversed with appropriate therapy. **Conclusions:** HDR Brachytherapy offers a highly effective treatment of skin carcinomas. Surface applicators, used with HDR brachytherapy equipment, enable a uniform dose distribution and sharp dose gradient at the edge of the

treatment field. Surface applicators are easy and safe to use and offer reproducibility for subsequent treatment fractions. These applicators have the ability to become the standard treatment for skin carcinomas in the near future.

SU-FF-T-257

How Useful Are DVH''s in IMRT Plan Intercomparisons?

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Purpose: To test the sensitivity of DVH-derived dose indices in comparisons of IMRT plans using different dose calculation methods. **Materials and Methods:** Eighteen Head-and-Neck IMRT patient plans are computed with SC and Monte Carlo (MC) algorithms using identical dose grid placement and resolution. Dose volume histograms (DVH) and resultant dose indices from each plan are evaluated for targets and critical structures as a function of the dose calculation method. The difference of the dose indices is tabulated. An alternate numerical method is introduced where the difference of the doses computed by the two methods are computed for each dose grid element, and divided by the average value at that point. Thereafter, the relative dose difference matrices are overlayed onto the 3D CT and contoured structures. The weighted average and standard deviation of the relative dose difference values over all points within each structure and target are extracted and compared to the dose index differences. **Results:** A linear regression analysis is possible between the average dose differences and the differences in the dose indices. However, the resultant fit shows a weak correlation, due to exacerbated standard deviations in the dose differences for all targets and dose-limiting structures. The large standard deviations reflect the differences in the location of hotspots and coldspots in the treatment plans derived from different calculation methods, which cannot be probed with DVH analyses. **Conclusions:** IMRT planning dose calculation may not be compared accurately with dose index analyses. Thus, we propose the implementation of a weighted dose difference analysis, beyond DVH analysis, for IMRT planning comparisons studies. The present method is an ideal evaluation tool in probabilistic planning and IGRT planning studies, where DVH analyses alone will be insensitive to differences in the location of hotspots and coldspots, within targets and critical structures. (Partial Support, NIH-1R01CA98524)

SU-FF-T-258

Hypofractionated Stereotactic Radiotherapy for Prostate Cancer Using the CyberKnife

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Purpose: To describe the investigational design, treatment planning, treatment delivery, and initial clinical results of a study on hypofractionated image-guided prostate cancer treatment using the CyberKnife. Design characteristics of the CyberKnife that enable real-time, 6-D fiducial tracking with sub-millimetric accuracy will be discussed. Treatment planning techniques, technical aspects of treatment delivery, and clinical outcome data will be presented. **Method and Materials:** Greater than 50 prostate cancer patients have been accrued. Patients were treated in five fractions of 7Gy each, for a total of 35 Gy over 5 to 7 days. Four fiducials were implanted using a transperineal approach. Technical details of each treatment were recorded along with treatment planning quality indicators. Follow-up clinical data were collected including PSA kinetics and rectal and urinary complications. **Results:** Data will be presented from MDACC Dosimetry Service that independently confirm the dosimetric accuracy and spatial precision of the CyberKnife system used in this study. Results will be presented summarizing the mean and range of technical and physical parameters used for this study: number of beams, number of nodes, number and size of collimators, treatment time, DVH indices, along with dose conformality and homogeneity indices. Typical intra-fraction drifts in prostate position detected by the real-time tracking system will be discussed. At the time of abstract submission, follow-up time for some patients exceeds twelve months. PSA and short-term morbidity data will be presented. **Conclusion:** This paper reports on the first clinical study of image-guided robotic x-ray therapy for the hypofractionated treatment of prostate cancer. The study has shown that accurate, spatially precise hypofractionated treatment can be delivered in a reasonable time using the CyberKnife. The study has shown that the short-term morbidity associated with this hypofractionated treatment regimen is very low. However, conclusions regarding long-term morbidity and biochemical disease-free survival will require significantly longer follow-up.

SU-FF-T-260

Image Fusion Reduces Errors for Mobile Tumors and Stereotactic Radiotherapy in IGRT

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Purpose: To evaluate set-up error for mobile tumors: lung, liver, and prostate under image-guided radiotherapy, and accuracy for cranial stereotactic radiotherapy with fixed (SRS) or removable frame systems (SRT). **Methods and Materials:** Twenty-six patients with lung, liver or prostate cancer were implanted with 3 gold markers inside in the tumors. Markers and planning isocenter coordinates were transferred to a fusion system. Patients were positioned according to skin tattoos and lasers followed by stereoscopic KV x-ray acquisition. The x-ray sets were then fused with corresponding digital reconstructed radiographs (DRRs) of the plan. New skin tattoos were made after fusion on the first treatment day. For extracranial treatments, markers were manually matched between the x-ray images and DRRs. Auto-fusion matching bone structures was applied for SRS/SRT. Deviations between actual and planning isocenters were determined by the fusion software. **Results:** Average prostate motions plus setup errors in the lateral, longitudinal and vertical directions were (mean $\pm$ one standard deviation): 3.0 ± 1.5 mm, 2.4 ± 1.0 mm, and 4.2 ± 1.8 mm, among 24 patients each treated with 25-45 fractions. Errors >10 mm in one of the three directions was found in 1.9% of the total 1773 measurements. Errors >5mm, occurred in 10.8%, but the rate reduced to 7.5% if 4 patients were excluded from the analysis. Errors for the lung following 32 fractions were: 3.3 ± 4.4 mm, 3.3 ± 2.9 mm, and 1.7 ± 1.2 mm. For liver the errors were: 4.2 ± 3.1 mm, 4.6 ± 4.6 mm, and 2.6 ± 2.7 mm. No error >2.0 mm occurred for SRS, but 15% exceeded 2.0 mm for SRT despite with good immobilization device. **Conclusions:** Use of image fusion provides a reliable method to evaluate quality of immobilization, verify and increase treatment accuracy. Results from this investigation may have implications for appropriate tumor margins for different sites and techniques.

SU-FF-T-261

Image Guided High Definition Dosimetry of IMRT Plans Using the MobileMOSFET System

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Purpose: To investigate the feasibility of using multiple MOSFET sensors, available with the mobileMOSFET® system as high definition dosimeter for IMRT plan verification. **Methods and Material:** Wireless dosimetry system (mobileMOSFET from Thomson Nielsen) was first tested for reproducibility, linearity, sensitivity, long-term performance, and angular dependency. Twenty head and neck plans, each consisting of 8-10 treatment fields were verified. Plans were generated in Pinnacle 7.6C, and exported to a cylindrical solid water phantom. The in-phantom dose distribution was calculated on the phantom CT image set, and two regions of interest were selected: GTV area and avoiding area. The doses at these points were measured using MOSFETs and compared to ionization chamber measurements and Pinnacle calculations. Site specific fixed configurations of 5 MOSFET positions has been developed, and ten patient plans were verified using this module. CBCT image guidance was used to accurately position the MOSFET phantom. **Results:** The response of MOSFET was found to be linear, reproducible (within ±2%), independent of angular positions (within ±2%) and stable with time. For 20 head and neck patients, average variations of (0.68±2.11)% at high dose point and (0.06±1.94)% at low dose point were observed between measured dose using MOSFET and ionization chamber. Average variations of (0.73±1.85)% and (0.96±2.00)% were observed between measured dose using MOSFET and plan dose at high and low dose points respectively. A (0.47±2.45)% variation was observed using the special insert for head and neck and prostate plans in four points out of five. **Conclusions:** These investigations indicate that the use of mobileMOSFET device with image

guidance would be suitable for efficient and high-resolution dose verification of complex IMRT plans.

SU-FF-T-262

Image-Guided Non-Invasive Stereotactic Radiosurgery

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Purpose: The objective of this study is to demonstrate that the use of image registration and a non-invasive head frame for SRS can achieve the same accuracy as the current invasive head-ring SRS technique. **Method and Materials:** First, a head phantom was used to evaluate the accuracy of this procedure for aiming the target. Then, two SRT patients fixed with the GTC frame were treated with the proposed technique for ten treatments. The five-point GTC alignment device was used to aid the repositioning of the GTC frame with respect of the original setup. This alignment device minimized the misalignment of the GTC frame in AP, lateral, and axial translations and the angular deviations about each of these axes on roll, tilt, and spin. Prior to each treatment, a daily CT scan with a localization device was acquired. Daily CT images were registered with planning CT and MRI images. The 9 rods on the daily CT images were then identified, such that all the target, critical structures, and external contours from the planning images were transferred to the daily stereotactic coordinates. A new plan was generated. **Results:** In the head phantom study, the daily isocenter setup was verified to be within 0.2 mm accuracy based upon the portal images verse the planned DRRs. Optimized the dose distributions for each daily CT images of ten treatments, the mean deviations of the daily isocenter from the planned isocenter are 0.2±0.12, -0.4±0.24, and -0.1±0.07 mm in AP-, LAT-, and VERT-direction, respectively. The comparison of dose-volume histograms is clearly revealed the prescribed dose enclosed the PTV for every treatment. **Conclusions:** The image-guided noninvasive frame SRS has the capability of delivering high level accuracy of dose to the lesion without the discomfort from the pins fixed to the patient's skull.

SU-FF-T-263

Imaging with Brachytherapy Sources

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Purpose: To demonstrate the concept of 2D projection and 3D volumetric imaging using brachytherapy treatment sources in patient prior to or during treatment. **Method and Materials:** As shown Figure 1, an Ir-192 HDR catheter is placed at 15 cm depth (a reasonable value for pelvic site) in a solid water phantom. XV films are placed on top of the phantom to capture 2D projection images. Vertebra-like structures serving as anatomical landmarks are placed at mid distance between the catheter and film. **Results:** The structures are clearly shown on the projection film with a dwell time of 600 seconds. Projection image acquisition time on the order of seconds or less is achievable with more sensitive (100 times more) detectors such as silicone flat panels and detectors used in SPECT cameras. The projection of the landmark coincides with the reference mark when the source is at the correct dwell position and is off the mark when the HDR source is away from the correct dwell position, as shown in Figure 1b and 1c. Thus a "port film" approach can be developed to verify the source position prior to treatment. With the possibility of verifying one dwell position against its reference mark, all other dwell positions can be verified against its own the reference mark. This provides a way of dynamically tracking the dwell positions of a multiple dwell position treatment plan. With projections taken at multiple angles with sensitive detectors at a fraction of a typical therapeutic dwell time, it will be possible and useful to obtain volume images of the treatment sources superimposed on anatomy, using tomographic (CT, SPECT, tomosynthesis) reconstruction methods. **Conclusion:** Three dimensional volume imaging with a HDR treatment source has been demonstrated. The concept applies to other brachytherapy modalities, e.g., SPECT for permanent prostate implants, LDRs.

SU-FF-T-264

Impact of Heterogeneous Activity Distributions On the Tumor Absorbed Dose Distribution for An In-Vivo Colorectal Cancer Model

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Purpose: To compare the heterogeneous uptake distribution of intact and domain deleted monoclonal antibodies with simulated activity distributions used to derive the dosimetric impact of heterogeneous uptake. **Method and Materials:** A total of 4 tumors with approximate masses of 0.1 g (~5mm diameter) and 0.5 g (~10mm diameter) were chosen for this study. Tumor activity distributions were reconstructed in 3D using serially sectioned LS174T tumors grown on the flank of athymic nude mice. The mice received an injection of either 177Lu-PA-DOTA-HuCC49 or 177Lu-PA-DOTA-HuCC49dCH2 monoclonal antibody. Simulated distributions of similar dimensions were created for comparison. All distributions were normalized to 100 uCi/g uptake and convolved with dose point kernels for a short range (I131) and a long range (Y90) isotope. Compared were radial profiles for activity density and dose rate, mean dose and tumor central dose. **Results:** The activity distributions are much more erratic for tumor uptake compared to the simulated distributions. There is also variation in minimum and maximum activity density between tumors. The simulated distributions under-estimated the tumor size dependence of the average dose for both isotopes by about 10%. The central dose for the small tumor were overestimated for Y90 and bracketed for I131. The central dose for the larger tumors was under-estimated for both isotopes. **Conclusion:** The simulated distributions did not well represent the large variation in uptake observed in tumors. Compared to the simulated distributions, dose due to Y90 performed better for the 0.5 g tumors, but worse for the 0.1 g tumors and dose due to I131 performed better for the 0.5 g tumors and similar for the 0.1 g tumors. The heterogeneity of uptake in tumors are not well represented by a single simulated distribution because of the wide variation in local uptake

SU-FF-T-265

Impact of Linac Isocenter Shifts On Stereotactic Radiosurgery Dose

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Introduction: Of the various sources of error in Stereotactic radiosurgery, linac isocenter shift can be the largest. We present a method of quantifying this error using Winston Lutz (WL) QA films and evaluate its impact on patient dose. **Methods and Materials:** WL films (5mm ball and 10mm cone) were acquired for 16 gantry and couch angles for a NOVALIS linac. Films were scanned at high-resolution (89 μm) and analyzed using RIT software to determine differences between ball and radiation field centroids. An algorithm was developed to transform these to patient reference frame and map out shifts between target and linac isocenter for all allowed gantry and table angles. For this study, a patient with trigeminal neuralgia (70Gy with 6 arcs and 4mm cone) was considered. The impact on delivered dose was evaluated by weighting each treatment arc with its appropriate isocenter shift. Also for comparison, the treatment plan was recalculated using the maximum shift observed in film data. **Results:** Minimum target dose (Dmin) in the original patient plan was 54.6Gy and target D95 was 61.6Gy. When maximum shift was used to modify treatment plan, DVH data erroneously showed 30% target underdosage: Dmin = 38.5Gy; D95 = 44.2Gy. However, for the "weighted-arc" plan, Dmin = 53.9Gy and D95 = 61Gy were within 1% of the original plan. Therefore, in evaluating dose delivered to the patient, it is important to consider the impact of isocenter shift on each treatment arc for highly accurate treatments. In appropriate cases, this method can also be used to compensate for gantry-table combinations that may fall outside the acceptable limits (> 1 mm). **Conclusions:** We have presented a method that allows quantitative evaluation of dose errors that result due to shifts in linac isocenter as a function of gantry and table angles.

SU-FF-T-266

Impact of MLC Leaf Size On the Quality of IMRT Plan

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Objective: For a given set of constraints, IMRT optimization searches for a minimum of the cost function to within the user specified convergence limit. The efficacy of segmentation and subsequent delivery may be dependent on the design and the leaf width of the MLC. The objective of the present study is to investigate if leaf resolution affects the quality of the treatment plan. **Materials & Methods:** Two accelerators with different MLC leaf resolution (10mm and 5 mm) are chosen in this study for three different cases (prostate, lung and head and neck). The dosimetry of the two machines are identical to within ±1%. With identical beam angles and dose grid (2 mm), IMRT plans are generated for the same set of constraints

for both machines. The DVHs of the PTV and the relevant organs-at-risk (OAR) are compared. **Results:** Figure 1(a, b, c) shows the DVH for prostate, lung, and head and neck. There are very little differences between PTV coverage and OARs except for small structures (<2 cm^3) for which the differences are appreciable. **Conclusions:** For treatment sites which involve small structures (volume< 2 cm^3), the use of 5 mm MLC is more beneficial as demonstrated in this study in the head-and-neck IMRT. For IMRT treatments with reasonable size OARs, MLC resolution does not appear to be a significant factor for all practical purpose. Thus in general, IMRT optimization and segmentation is relatively insensitive to the leaf width.

SU-FF-T-267

Implementation of ATC Method 1 for Clinical Trials Data Review at the Quality Assurance Review Center

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Purpose: To develop the capability at the Quality Assurance Review Center (QARC) to receive and review digital radiation therapy treatment planning data (TPD) for clinical trial case review. **Method and Materials:** A system of software ("ATC Method 1") developed at the Image-guided Therapy QA Center (ITC) as part of the Advanced Technology QA Consortium (ATC) to receive, process, and review volumetric TPD for clinical trials was ported to a Linux workstation at QARC. The system includes an FTP server for receiving TPD (in DICOM or RTOG data exchange format) from protocol participants, utilities for importing TPD into a local file format, and the web-based Remote Review Tool (RRT) for QA of ROIs, isodoses, DVHs, and dose statistics. (Proprietary software components were used by special arrangement with CMS, Inc.) **Results:** Software installation and maintenance were performed remotely at QARC by ITC personnel, with weekly teleconferences to coordinate the development effort. ITC software was adapted to better support the QARC QA process. RRT enhancements include selectable DVHs, distance measurement tool, and image grayscale presets. QARC software was adapted to support RRT invocation directly from the QARC database user interface. The system is in use for six COG, CALGB, ACOSOG, and ECOG protocols; 28 cases from 15 institutions have been received and reviewed (3/1/06). **Conclusion:** Widespread use of new treatment modalities such as IMRT, makes use of 3D datasets essential for complete evaluation of ROI delineation and assessment of agreement of dosimetric parameters with protocol requirements. This project demonstrates that ATC Method 1, successfully used in support of RTOG trials for many years at ITC, can be implemented at other QA centers. The effort required, however, was significant and tools must be tailored to each individual QA center's computer infrastructure/QA process. Supported by NIH U24 Grant CA81647 and NCI-H Grant 5U10CA02951.

SU-FF-T-268

Implementation of Good Laboratory Practice Standards for Improving Dosimetry in Radiobiology Lab

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Purpose: Accuracy of radiation dosimetry in radiobiology lab needs to be improved so that the results can be reproduced at different labs and translated into clinic. In this work we establish dosimetry procedures and improve accuracy of radiation delivery in a radiobiology lab based on the Good Laboratory Practice (GLP) requirements. **Method and Materials:** GLP guidelines and AAPM protocols were used to collect dosimetry data and to establish dosimetry procedures for routine quality assurance and for documenting delivery dose. A radiation field analyzer (Scanditronix) was used to characterize x-ray beams produced by a Pantak HF320 orthovoltage system in the Radiobiology lab of the Medical College of Wisconsin. The relative dosimetry data were measured with an ionization chamber suitable for the kilovoltage x-rays. A software method was developed to generate 3D isodose distributions. The absolute dosimetry measurements were performed using a Farmer ionization chamber calibrated in a standard dosimetry lab. The absolute doses were determined using the AAPM TG-61 protocol. The QA procedures were established according to the GLP standards and based on AAPM TG-40 protocol. **Results:** Accurate relative dosimetry data including depth doses, profiles, and isodose distributions for a variety of energies, filters, collimators and source-to-surface distances were obtained. Isodose distributions were generated for various opposite parallel fields irradiating phantoms with different thicknesses. Absolute doses were determined for a series of irradiation situations. These data facilitated accurate planning of animal irradiations and documentation of the delivered doses. Periodic QA procedures were established. **Conclusion:** We have collected essential dosimetry data and have established procedures for routine QA and dose documentation under the GLP standards. Thereby we improved the dosimetry in the Radiobiology lab to the level seen in the clinical setting. This work will facilitate accurate dose delivery, reproducibility of the results, and direct transfer of animal data into the clinic.

SU-FF-T-270

Implementing a Monte Carlo Algorithm for Fields with Dynamic Beam Modifiers

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Purpose: Monte Carlo methods for photons are slowly becoming available for normal clinical use. Especially for dynamic or otherwise complex fields Monte Carlo methods can be superior to traditional methods. The time to compute a Monte Carlo dose distribution up to a given accuracy is nearly independent of the complexity of the whole plan. Instead, traditional methods usually require computation time directly proportional to the complexity of the treatment. In this work, VMC++ (Voxel Monte Carlo, National Research Council, Canada) algorithm for fields with dynamic beam modifiers has been implemented. **Method and Materials:** A Monte Carlo implementation of an accelerator head model for dynamic fields is presented. Cases studied include dynamic wedges, sliding window IMRT fields, and complex arc fields. Except for dynamic wedges, the transport through the relevant components is modeled using VMC++. Tongue-and-groove, air cavities, divergent leafs, and rounded leaf tips in a multi-leaf collimator are taken into account. In the case of dynamic wedges the jaws are modeled as impenetratable blocks. The final patient dose calculation is also done using VMC++ algorithm. **Results:** Results are presented for each of the dynamic components by comparing the Monte Carlo calculated data to measurements. The agreement is excellent in all cases. The calculation time varies from a few minutes to a few hours, depending on the required accuracy and target volume. **Conclusion:** Monte Carlo is shown to be a very competitive alternative for traditional methods in modeling accessories, especially for dynamic treatments. The results of the corresponding dose calculation match very well with measured beam data. In addition, the obtained execution times are suitable for routine clinical use. **Conflict of Interest:** This work has been funded by Varian Medical Systems Inc.

SU-FF-T-271

Implementing a Parallel Monte Carlo System as a Clinical Treatment Planning System Validation Tool

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Purpose: We present the implementation of an automated EGSnrc-based Monte Carlo (MC) system within a parallel computing environment as a tool for validating the dose distributions produced by a clinical treatment planning system (TPS) for external beam radiotherapy. **Method and Materials:** A clinical plan is generated on Varian's Eclipse TPS, which produces a set of DICOM RT data objects: RT Plan, RT Structure Set, RT Dose and a CT image set. MC simulation parameters are read and calculated from the DICOM RT objects. The CT image set is then used to generate a virtual phantom in a manner analogous to that of CTcreate (the relevant EGSnrc program), but with the added advantage of incorporating the structures in RT Structure Set for volume definition within the phantom. The MC simulation is broken into stages that progress from the target in the head of the accelerator (modeled explicitly), through the various stages of collimation, and into the phantom using both BEAMnrc and DOSXYZnrc on a dedicated cluster of 18 processors. Using RT Dose, we compare absolute dose differences between the TPS and MC quantitatively in 3D using a χ metric. To illustrate the implementation, we compare dose distributions for an unblocked four field pelvis plan at 15 MV. **Results:** Simulation of the complete plan took < 7 hours, achieving statistical uncertainties of ~1.6% for each field (at isocenter) in 2.5 ×.2.5 ×

3 mm^3 voxels. Within the body contour 98.4% of the MC dose voxels agree with the TPS (2%/2.5 mm criteria). Significant differences (> 4%) are observed around the bony anatomy. **Conclusion:** This work establishes a framework for the full clinical implementation of MC as a tool for TPS verification.

SU-FF-T-272

Implication of CT Couch Sag On Geometrical Accuracy During Virtual Simulation

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Purpose: Advances in radiation therapy have increased the need for better patient positioning accuracy. We have measured and compared the degree of couch sag exhibited by various CT scanners at our institution, and have evaluated its implication. Methods and Materials: Six CT scanners, a GE LightSpeed RT wide bore scanner, a GE LightSpeed RT standard bore scanner, a GE LightSpeed PET/CT scanner, a Philips wide bore scanner, a Philips MX-8000 IDT scanner and a Picker PQ 5000 scanner were evaluated for couch sag. In order to simulate the weight distribution of a patient, five large water bottles, each weighing 43.3 lbs, were placed evenly across the couch. To quantify sag, a laser QA phantom was placed at locations on the couch, corresponding to the approximate location of three commonly scanned regions of the body: head/neck, thorax and pelvis. Using virtual simulation software, the vertical position of the phantom alignment point inside the CT bore was determined, and then compared to the starting vertical position of the external reference laser. This comparison yielded the amount of couch sag under a clinically representative weight distribution. **Results:** Results indicate that the amount of couch sag ranged from approximately 0.7 mm to 6.6 mm. As expected, couch sag varied with anatomical region. In addition, the amount of sag varied between different manufacturers, and between couches of the same model as well. **Conclusion:** Failure to recognize this problem could lead to incorrectly derived isocenter localization, and subsequent patient positioning errors. The amount of sag should be measured under a clinically representative weight load upon CT-simulator commissioning. We are evaluating ways of incorporating these couch displacements into our virtual simulation process.

SU-FF-T-273

Improved Calculation of Energy Spectra From Electron Depth Dose Curves

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Purpose: Improve the precision of response functions, account for scatter in air, and significantly reduce the scatter component of the beam. **Methods and Materials:** (1) The electron depth dose measurements that are used as the reference are an open field (40cm x 40cm) without any applicator. (2) The vacuum in the space between source and phantom has been replaced with air, to account fully for in-air scatter. (3) The point source simulation with a set of small scoring regions around the central axis has been replaced by a 0.001 cm radius pencil beam simulation on a single 100 cm radius voxel. This is equivalent to a broad beam normally incident on the phantom with small scoring area. The resulting depth dose curves are corrected to a point source with an inverse square law correction. Ds(d) is the simulated dose at depth d in a 100 cm SSD setup. The corrected dose Dc(d) can be found with: Dc(d)=Ds(d)*10,000/(100+d)^2. **Results:** The electron depth dose curves simulated with a small pencil beam and large planar scoring regions agree well with those simulated with a point source and small regions after the inverse square law correction has been applied. The simulation times for the pencil beam calculations were shorter by orders of magnitude and the precision is much better. Use of the large field with very low scatter from peripheral components and including the air scatter in the response functions provides for a more realistic estimate of the true spectrum. Otherwise the low energy component is overestimated. **Conclusions:** The three improvements of the unfolding procedure improve the accuracy of the electron spectra and require less simulation time.

SU-FF-T-274

Improvements of a Commercial Treatment Planning System On the MLC Field

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Purpose: A recently released Pinnacle treatment planning system software, v7.4f includes some new physics features such as modeling of the rounded multi-leaf collimator (MLC) leaf ends and the tongue-and-groove structure between leaves. In this study, the above physics modeling improvements were verified by comparing the peripheral dose profiles for the small MLC fields calculated by the new Pinnacle v7.4f and the old Pinnacle v6.2b with those obtained from measurements experimentally. **Method and Materials:** Three test MLC fields with different jaw sizes were prepared, and specific dose profiles (along cross-line, in-line and diagonal axis) at different depths were measured using a Varian 21EX linear accelerator with 120-leaf Millennium MLC, big scanning water tank and photon diode. Estimated dose profiles for the test fields were calculated using Pinnacle v6.2b and v7.4f. **Results:** By comparing the measured and calculated results, both v6.2b and v7.4f performed well in calculating the cross-line (along the gap between the longitudinal lengths of two leaves) and diagonal axis dose profiles at different depths. However, v7.4f gave calculated doses closer to the measured field for in-line (gap between junctions of two rounded leaf ends) axis dose profiles at different depths. For the shape of profile along the in-line axis, v7.4f calculated a flat "platform" dose profile of about 34.3% (inter-bank leakage) at depth d_{max} beyond the MLC field edge using a clinical dose grid size of $0.4 \times 0.4 \times 0.4$ cm^3, compared to the "zigzag" dose profile varying between 35.4% and 42.1% measured using water tank and diode. However, both versions calculated the percentage depth dose for the test fields well compared to the measurements.**Conclusion:** The physics improvements of the rounded leaf end, tongue-and-groove structure, inter-leaf and inter-bank leakage corrections as new features of v7.4f were verified.

SU-FF-T-275

Improving IMRT Plans Delivery for Head and Neck Cases Using Aperture-Based MLC Segments

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Purpose: To investigate the possibility of performing IMRT in head and neck treatment sites with less segments and monitor units (MU). **Materials and Methods:** Six pharyngeal cases (n = 6) were analysed and four cases (n = 4), in the sinonasal region. For each one, an IMRT plan was first realized using a commercial software (P^3IMRT, Pinnacle[3] – IMFAST segmentation algorithm). These patients had to receive 32 fractions of simultaneous integrated boost external beam radiotherapy at 1.8 and 2.15 Gy/fraction, respectively to the low and high risk planning target volumes (PTV1 and PTV2). Then, an-in-house inverse planning system, called *Ballista*, based on predetermined segments, was used to realize comparable plans. Its segments are generated with the subtraction of the projection of the OARs with the PTV (planning target volume). **Results:** For the pharyngeal *Ballista* plans, the average volume of the PTV that received at least 100% of the prescribed dose (V_{100}) was 85.0±4.5% for the first prescription (PTV1) and the V_{100} for the second prescription (PTV2 – simultaneous integrated boost –) was 78.5±10.9%. With Pinnacle[3],the V_{100} value was 86.6±4.8% and 81.5±12.4% respectively for PTV1 and PTV2 (see figure 2a and 2b). On average, *Ballista* plans have required 932±124 MU and 52±10 segments compared to 1238±230 MU and 117±7 segments for Pinnacle[3]. For the sinonasal *Ballista* plans, the average V_{100} obtained was 80.0±3.1%. With Pinnacle[3], the V_{100} gave 75.7±2.7%. *Ballista* plans have required an average of 406±54 MU and 22±1 segments compared to 697±133 MU and 99±14 segments for beamlet-based IMRT. **Conclusion:** In step-and-shoot head and neck IMRT, an anatomy-based MLC optimization system can achieve similar dosimetric plans comparable to traditional beamlet-based IMRT with less number of segments and MU.

SU-FF-T-276

Improving the Accuracy of Linac-Based Stereotaxy

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Purpose: Stereotactic alignment accuracy of couch mount linac systems can be improved by analyzing the film test with a computer program and repositioning the setup appropriately. **Method and Materials:** The Winston-Lutz style film test is scanned and analyzed with a computer program that can estimate the 3D alignment error of the stereotactic quality assurance (QA) setup to within 0.1 mm. The program gives repositioning advice, and digital cameras are used by another program to provide laser guided repositioning. A final film test is taken whenever the couch mount needs to be repositioned. The programs remember laser, cone, and gantry offsets, so if the system is used frequently enough the laser guided repositioning often makes it possible to get within 0.2 mm of isocenter on the first couch mount film test. This system can make the couch mount more accurate than the mechanical isocenter standard (MIS). When the MIS has alignment problems it typically takes weeks or months to resolve, and often a site visit from a field service engineer is required. Conversely, our new approach adapts every treatment day to slight gantry, couch, and collimator movements, and always adapts to minimize the overall alignment error. **Results:** Clinical tests with a Varian 600c at Mercy Hospital in Scranton, Pennsylvania, and a Siemens Mevatron MXE 2 at Christiana Care in Newark, Delaware have shown that 0.2 mm isocenter alignment of the couch mount QA setup can be achieved using this system. This is 7.5 times more accurate than the current 1.5 mm radial alignment specification of a commercial linear accelerator based stereotactic system. **Conclusion:** This research shows the potential of linac based stereotaxy to approach the accuracy of the dedicated stereotactic systems.

SU-FF-T-277

IMRT Composite Plan - A Must Tool for Final Dose Analysis with IMRT Boost Plan

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Purpose: To observe the IMRT composite planning results from two different dose object functions and to suggest the adequate methodology for plan evaluation. **Method and Materials:** IMRT treatment planning often presents a two-steps process; initial plan to cover the gross tumor disease and potential nodal areas; then the Cone Down (CD) plan for gross tumor boost. IMRT CD plan usually is a great challenge to generate the composite dose distribution due to its dose non-uniformity nature for IMRT planning. Quality of the composite IMRT plan can be greatly influenced by the initial treatment planning due to its non-uniform dose distribution nature to add on the CD IMRT plan. Since there are still a few planning systems not even provide the composite dose options for summarizing the initial IMRT plan with IMRT CD plan. We are currently using the Pinnacle system to analyze composite dose effects by using the total dose constraints as well as the separate dose constraints. **Results:** Clinical findings are summarized as 1) Initial IMRT and CD IMRT plans are highly correlated and the dose constraints have to be considered in a composite way (see fig. 1 (composite dose constraints) and fig. 2 (CD dose constraints)); 2) A sub-optimal initial IMRT plan can disturb the IMRT CD plan for composite dosimetry, creating a unacceptable MUS due to the non-uniform intensity map summarization (figs. 3 and 4 shows high MUS to compensate the PTV coverage compared to figs. 5 and 6) ; 3) Scaled CD IMRT dose constraints may not generate an acceptable composite dose distribution since summation of the two acceptable individual intensity maps may not create an optimum composite intensity to meet the final dose criteria. **Conclusion:** From planning comparison, composite IMRT plan has to be analyzed in order to create the true dose distribution in IMRT.

SU-FF-T-279

IMRT Plans Can Be Simplified Using One-Step Optimization

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Purpose: To compare the effectiveness of one-step optimization (DMPO) to traditional two-step optimization for IMRT planning for prostate cancer, and to test the feasibility of simplified IMRT plans for reduction of delivery time and background dose without significant degradations in plan quality. **Method and Materials:** Clinical plans for five patients were created using DMPO with the maximum number of segments set at 40. Three additional plans were created using a leaf sequence converter with the same planning objectives. The number of levels was set to 10, 5 and 3 with corresponding number of extracts set at 5, 3 and 2, resulting in plans with decreasing numbers of segments. All plans were normalized so 95% of each target volume (prostate, lymph nodes and seminal vesicles) met the prescribed dose. Plan quality was assessed based on tumor coverage, defined endpoints for sensitive structures, plan dose conformality and dose homogeneity. **Results:** The DMPO plans resulted in the lowest average number of segments at 38.8, compared to 160.4, 77.2 and 45.4 for the two-step plans, and also had the highest overall plan quality. The DMPO plans resulted in the lowest D5 and D20 to the bladder, the lowest D20 to the rectum and the lowest V45 to the small bowel. In addition, the DMPO plans had the lowest number of monitor units at 745.8, compared to 910.6, 893.6, and 823.2 MU respectively for the two-step plans. The DMPO plans had an average homogeneity index of 89%, compared to 90%, 88% and 83%, and a conformal index of 2.9 compared to 2.8, 3.9 and 4.8. **Conclusion:** One-step optimization is an efficient and effective way to create simplified IMRT treatment plans. For prostate cancer patients treated with IMRT, clinical requirements can be met with 40 or fewer segments using DMPO.

SU-FF-T-281

In Vivo Dosimtery for IMRT Treatments Generated by Pinnacle Treatment Planning System

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Dose verification using diodes has recently been proposed for IMRT treatments and has been evaluated for IMRT deliveries planned using the Eclipse treatment planning system. The Pinnacle treatment planning system generates plans that are delivered in a different fashion than Eclipse. Whereas the Eclipse-generated plans are delivered by scanning the treatment area from one side to the other, Pinnacle-generated plans are delivered in a seemingly random fashion, treating multiple small areas within the field. This makes diode measurements at a point potentially more uncertain since the diode may be exposed fully or partially to multiple small fields during one single field's treatment as opposed to being exposed to very few segments scanning the point during an Eclipse-generated delivery. We have evaluated in vivo dosimtery for Pinnacle-generated IMRT plans, characterized diode response to IMRT deliveries involving various beamlets and evaluated its response due to full or partial exposure to radiation. We will also present the results of diode measurements performed for 150 IMRT fields on patient and phantom.

SU-FF-T-283

In-Vivo Diode Dosimetry for IMRT Fields

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Purpose: In-vivo dosimetry can be a useful tool to verify overall patient treatment quality with respect to calculation, setup and delivery. We have conducted a study in our department using the Sun Nuclear QED diode detectors to verify the accuracy of dose delivery in patients undergoing IMRT treatments. The expected diode reading calculation is based on an in-house developed MU calculation program. **Method and Materials:** The diodes were placed on the surface of a 4 cm thick solid water phantom and the IMRT fields were delivered to the assigned SSD under treatment conditions. We compared the diode dose readings during the IMRT treatment delivery with the calculated entrance dose in the Penn MU program. The results were also compared with the Dose/MU ratio between PennMU and Oncentra treatment planning system (OTP). **Results:** A large number of cases were selected and 73 IMRT fields were checked. The calculated values were in 8% agreement with the diode readings. The magnitude of error is dependent on the diode position in the delivered field, whether it is located in a high or low dose region. Shifting the diode position to a high dose region lead to improved accuracy. **Conclusion:** Penn MU calculation program and the diode measurements are within 8% agreement and we expect our MU calculation program to be clinically used as a reliable tool for verification, keeping in mind that the diode point of measurement should be in a high dose region to avoid large errors.

SU-FF-T-284

Independent Calculation of Dose for a Helical TomoTherapy Treatment Plan

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Purpose: To develop a new calculation algorithm for independently verifying doses from helical TomoTherapy treatment plans. **Method and Materials:** The calculation algorithm confirms dose to a point in a high-dose, low-gradient region where modulation is expected to be minimal. Inputs to the algorithm are the coordinates of the point, the radiological depth for each projection angle in the axial plane of the point, and the treatment sinogram. The algorithm uses common dosimetric functions (e.g., TPR, S_{cp}), which were measured on the TomoTherapy treatment unit. Measured lateral and longitudinal profile data are used to quantify the off-axis dose dependence. Test comparisons were made using a 7-cm diameter PTV centered in a 20-cm diameter cylindrical phantom. The phantom was positioned in the center of the treatment bore for one test and 10 cm off-axis for another. Comparisons were also made for five prostate cancer treatment plans. In all cases, the point of calculation was the geometric center of the PTV. **Results:** Measurements of both TPR and S_{cp} on the TomoTherapy unit demonstrated small variation with jaw width (field length) and the number of open leaves (field width). Therefore, average values of TPR(d) and S_{cp} were used in the algorithm. Comparisons with the cylindrical phantom treatment plans demonstrated good agreement, with the calculated doses agreeing within 2% at the PTV center for both the on-axis and off-axis treatment plans. Results for the prostate patients also showed good agreement within 4%. **Conclusion:** A new calculation algorithm that uses standard dosimetric functions has been developed for verifying doses from helical TomoTherapy treatment plans. Supported in part by a research agreement with TomoTherapy, Inc.

SU-FF-T-285

Independent Monitor Unit Verification with the RadCalc® Program of Serial Tomotherapy IMRT Treatment Delivery

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Purpose: To present our initial experience with the implementation of commercially available independent monitor unit (MU) verification calculation software (RadCalc®) for dose verification for patients undergoing IMRT (serial tomotherapy) treatments planned using a commercially available IMRT planning system (CORVUS® 6.0) and delivered using the multileaf intensity modulating collimator (MIMiC) delivery device. **Method and Materials:** As a first step we defined a separate machine within the RadCalc® software to facilitate the dose verification process. At our facility, serial tomotherapy is used to deliver IMRT treatments. This is accomplished using the MIMiC delivery device attached to a Varian 600C linear accelerator producing a 6 MV photon beam. Dosimetric data for this treatment machine which included collimator and phantom scatter factors (S_c and S_p) and leaf transmission for the MIMiC were also incorporated in the RadCalc® Software. After the treatment plans are approved for treatment by the radiation oncologist a hybrid QA (quality assurance) plan is generated and delivered to an ion chamber and film placed in a rectangular solid water phantom of dimensions 30 cm x 30 cm x 22 cm. The phantom geometry was also defined in the RadCalc® software to facilitate dose calculation and comparison with the dose determined from ion-chamber measurements. In this preliminary study a total of 13 patients undergoing IMRT treatment with the MIMiC were analyzed. **Results:** Initial results indicate a good agreement (within ±5%) between dose calculated from the hybrid plan, ion chamber measurements, and the dose calculated by the RadCalc® program. **Conclusion:** Based on initial results presented here we have set an action level of ±5% which will be reviewed and revised as necessary as we continue to acquire and analyze additional patient data.

SU-FF-T-286

Inhomogeneity Correction in Brachytherapy

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Purpose: Dose calculation accuracy at interfaces and in medium with inhomogeneities is still not well established in brachytherapy. Commercial planning systems do not account for the presence of inhomogeneity, while theoretical calculations in inhomogeneities have poor agreement with measurements. The wide use of brachytherapy for breast, prostate, brain and lung treatment in recent development necessitates the need for improvement in brachytherapy dose calculations. In this study, we present an experimental approach to investigate the effect of inhomogeneity for Ir-192 and Cs-137. **Method and Materials:** To study the effect of lung in brachytherapy dose calculation, measurements are performed in a polystyrene phantom embedded with cork sheets of density 0.25 g/cm^3. Radioactive source used in the study are Ir-192 (HDR source) and Cs-137 tube. Two conditions are studied, one mimics the partial breast treatment with the Mammosite technique, and the other brachytherapy in lung after wedge resection. Dose is measured with a small volume parallel plate ion chamber, embedded in polystyrene or in cork by varying the position of the chamber from the source. Inhomogeneity correction factor (ICF), defined as dose in inhomogenerity / dose in water at the same distance (D_i/D_w) is calculated. **Results:** The calculated ICF values qualitatively agree with our measured values. However there are significant differences that could be due to inaccuracies in build up factors and other assumptions made in the calculations. The dose in medium falls exponentially with distance. The measured ICF is strongly dependent on the position and energy. For example, at 2 cm, ICF for the full inhomogeneity condition is approximately 3.5 and 8.5 for Cs-137 and Ir-192 respectively. **Conclusions:** The magnitude of correction is significantly dependent on the distance and energy as well as the condition of partial or full inhomogeneity. TPS vendors should provide ICF for all commonly used brachytherapy sources.

SU-FF-T-287

Inhomogeneity Effect On Gamma Knife Stereotactic RadioSurgery

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Purpose: To study the inhomogeneity effect from skull and air cavity on Gamma Knife Stereotactic Radiosurgery. **Method and Materials:** Patient CT data from Gamma Knife procedure was used in a Monte Carlo simulation. In the Monte Carlo simulation, the 201 Cobalt-60 sources were considered to have the same activity. Each Cobalt-60 source was contained in a cylindric stainless steel capsule. The beam data was stored in four beam phase-space files which were generated in the inner side for each of 4 treatment helmets, after the Cobalt beam passed through primary collimator and secondary collimator. The dose was calculated using Monte Carlo simulation in both homogenous and inhomogeneous geometries rebuilt from patient CT data with identical beam parameters. A small volume was created around the iso-center for DVH comparison. The doses in a 16cm diameter spherical QA phantom were also measured and calculated with and without 1.5mm Lead-covering. **Results:** For QA phantom, the dose ratios with and without 1.5mm Lead covering are 89.8% from measurement and 89.2% from Monte Carlo. For patient's CT phantoms, Monte Calor results show that although the isodose lines remain almost the same with and without inhomogeneity correction, the difference in absolute dose has been observed. The dose in CT phantom is about 4.1% lower than the dose in water replaced CT phantom. With various skull densities, the inhomogeneity effect could reach as high as 8.0%. **Conclusion:** Monte Carlo has been applied to dose comparison for CT image with and without inhomogeneity correction. Monte Carlo simulation matches very well with measurement for the spherical QA phantom. It shows that the implementation of Monte Carlo simulation for Gamma Knife is accurate. It shows that the inhomogeneity effect should be considered for gamma knife treatment planning.

SU-FF-T-288

Initial Experience with a Commercial Monte Carlo Electron Treatment Planning System

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Introduction: Monte Carlo modeling of clinical electron beams has the potential to substantially improve accuracy and quality of treatment planning, as excessive compute time and lack of commercial availability has hindered its application. Here we present a preliminary evaluation of a

commercial electron Monte Carlo algorithm. **Methods and Materials:** Percent depth dose and profiles of 6-20 MeV electrons and 6x6 – 25x25 cm cones were measured in a water tank at 100 cm SSD using a Farmer chamber for electrons. Absolute output was measured at 110 and 100 cm SSDs. Outputs and distributions of two extreme test cases were measured: a 2.1 cm x 3 cm insert in a 6x6 cone and a 2.8 cm x 15.7 cm long slit on a 25x25 cone. The algorithm's ability to accurately model relative and absolute dose of an obliquely (30°) oriented beam was evaluated ionization chamber measurements. Clinical cases with were checked using Mosfet dosimeters *in vivo*. Monte Carlo calculations were performed with a 2 mm grid, and smoothing filters provided with the algorithm were applied to minimize noise in the data. **Results:** Agreement of 2% of measured and modeled doses was found over the evaluated range of energies, cones, obliquities and SSDs. Compute times of 1-5 minutes were a function of increasing field size. Visual comparison of the shapes of the profiles was in agreement with measurement. Profiles of the eccentric geometry test cases appeared to be to be physically unrealistic (e.g. an inverted V) in the smaller dimension suggesting that the beam model was not valid. **Conclusions:** The Monte Carlo electron algorithm provides accurate distributions for most clinical cases. For extreme cases, measurements should be made to test the accuracy of the system, and further development of the algorithm is recommended.

SU-FF-T-289

Initial Study On the Dose Evaluation of Boron Neutron Capture Synovectomy Using THOR Epithermal Neutron Beam

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Purpose: To evaluate the feasibility of Boron Neutron Capture Synovectomy by Tsing Hua Opening-pool Reactor (THOR) in Taiwan and to determine the optimal treatment parameters with epithermal neutron beam. **Method and Materials:** MCNP5 was used to model the THOR epithermal neutron beam interactions with knee and finger phantom. The phantom was established according to the structure of human joints with different boron concentration. The treatment parameters were used to model the optimum treatment assembly, such as different thickness of reflectors and beam orientations. The Figure of merits (FOMs) such as total treatment time, total maximum skin dose and synovium to bone treatment ratio were used to evaluate the effect of the treatment parameters. **Results:** Monte Carlo calculations predict a total therapy time of BNCS between 5 and 15 min for the human knee by optimum THOR beam assembly. The treatment parameters of BNCS vary with joint sizes. The optimum treatment condition for different joint size can be achieved by using the opposed parallel beam, placing the inflamed joint near the source, and adding 10cm side and rear graphite reflectors. To compare with BNCS using the neutron beam produced by accelerator, the THOR epithermal beam will reduce the total skin dose from 205 RBEcGy to 130.24 RBEcGy and increase the TR_{bone} from 72 to 74.28. **Conclusion:** This study predicts the optimum THOR beam assembly for BNCS. The result shows the quality and overall clinical efficacy of THOR epithermal neutron beam for BNCS is more suitable than the beam produced by accelerator. It provides the potential application of BNCS by epithermal neutron beam.

SU-FF-T-290

Integration of AAPM TG-43 Formalism Into a New Plastic Scintillator Dosimeter System

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Purpose: To integrate the AAPM Task Group 43 (TG-43) brachytherapy dose calculation formalism directly into a new plastic scintillator dosimeter system. **Method and Materials:** A novel plastic scintillator system specifically designed to obtain the dose distribution in three dimensions in real time around low-energy x-ray-emitting prostate brachytherapy seeds has been constructed. The small sensitive volume (0.5 mm diameter x 0.5 mm thick) allows unprecedented resolution in dose-mapping of brachytherapy sources. High sensitivity is achieved by proprietary electronic signal acquisition and processing methods, allowing measurements of the very low dose rates (down to 1 mGy / h) at distances of up to several centimeters from a seed mounted in a water phantom. The computer program that controls this automated dosimeter system has been designed to acquire and display data directly in the format specified by the AAPM TG-43 protocol for calculating brachytherapy seed dose distributions in terms of radial dose function and anisotropy function. **Results:** The dose distributions around typical I-125 and Pd-103 prostate brachytherapy seeds have been measured. A comparison of the results to published TG-43 data for several seed models shows excellent agreement in most cases. Anisotropy functions at distances closer to the seed than those published for thermoluminescent dosimeter (TLD) measurements of an I-125 seed have been measured. In one case, use of this dosimeter allowed the rapid identification of a seed with an anomalous anisotropy function, later confirmed by a radiochromic film contact-exposure measurement. **Conclusions:** The automation of this new, high sensitivity, high-resolution plastic scintillator dosimeter, incorporating the TG-43 dose calculation formalism, has allowed real-time characterization of the dose distribution around prostate brachytherapy seeds in a liquid water phantom. **Conflict of Interest:** This work supported by NIST SBIR Grant SB1341-03-W-0815 and NSF Grant Nos. 0097450 and 0453430.

SU-FF-T-291

Intensity Map Verification for IMRT QA Using An A-Si EPID

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Purpose: To use a flat panel electronic portal imaging device (EPID) for intensity map verification as part of an intensity modulated radiation therapy (IMRT) QA program. **Method and Materials:** An a-Si EPID was used to image each field shape segment of a head and neck IMRT treatment. The DICOM images produced from each gantry angle were summed together and weighted according to the number of MU measured. Open field portal images were acquired at the end of the treatment, for each gantry angle, and subtracted from each composite image. A GUI was created in the MATLAB environment to read and sort each image according to gantry angle and MU measured, perform the image summations/subtractions, produce and display a final composite image. **Results:** Subtraction of the open field portal image from the field shape composite image removed the anatomy from the treatment area and produced a true intensity map. Outside of the treatment area the anatomy was visible, thus providing verification of correct radiation delivery location. The composite images were compared to other composite images produced using the same treatment plan delivered with and without a phantom and were found to be in excellent agreement. The images were also compared to the intensity map images created in the treatment planning system. Imaging of each segment of an IMRT treatment required no additional radiation be delivered to the patient. The open field portal images require additional radiation, however each image needs only to be acquired once during a course of treatment. **Conclusion:** This work indicates that flat panel EPIDs may be used to image an IMRT treatment and accurately and efficiently verify the intensity and location of the delivered radiation. Future investigations will use the 2D images to produce a 3D intensity "cloud" image.

SU-FF-T-292

Inter-Institution Comparison of Patient Quality Assurance Analysis for Tomotherapy

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Purpose: HiArt Tomotherapy unit has been used in the clinics for a couple of years. However, the patient-specific intensity modulated radiotherapy (IMRT) quality assurance (QA) methods vary from center to center. The purpose of this investigation is to analyze and compare the patient specific QA results for the HiArt TomoTherapy between two different institutions. **Method and Materials:** A patient-specific IMRT QA procedure was developed and implemented in two different institutions. Once a QA plan is calculated, the dose to a phantom is measured using ion chamber and film. The ion chamber is placed 5 mm below the film which in turn is placed in the equator of a cylindrical solid water phantom. After the plan is delivered to the phantom, the point dose is recorded and the film is processed. Dosimetric analysis is performed after the film and planar dose

are co-registered in the TomoTherapy planning station. In total, sixty-three patient QA from one center and fifty-four patients QA from the other were analyzed. **Results:** For 52.99% of QA measurements done, the difference between measured and calculated doses was less than 1%. In both centers, the patient specific QA tolerance is set to 3%. In total, 92.31% of patient specific QA can pass the QA. Failure to pass the QA can be attributed to: (1) setup uncertainty (2) resolution differences in scanned QA phantom (3) the machine output fluctuation. **Conclusions:** A comprehensive patient QA program has been developed and the results of 117 patients from two different centers are analyzed in this paper. Given the novel approach of TomoTherapy towards IMRT, it is important to see that for the majority of the patients the deviation between planned and delivered doses is less than 3%.

SU-FF-T-293

Inter-Linac and Intra-Linac Variability of X-Ray and Electron Dose Distributions

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Purpose: To determine the maximum expected variation in fluence, differential in energy and position, with an accuracy of 1% for a single linac model, and eventually, combining with Monte Carlo beam models, to develop gold standard beam model benchmarks. **Method and Materials:** The 6 and 18 MV beams of the Siemens Primus linear accelerator (linac) were tuned through the manufacturer acceptance range in field flatness by adjusting beam energy. Dose profiles were measured at the low, high and average energy in this range for small, medium and large field sizes to quantify the intra-linac variations caused by energy adjustment. The 6 and 18 MV x-ray beams, and 6-21 MeV electron beams on three Primus machines, with the same treatment head, were tuned to give the same central axis depth dose curves to better than 0.5% for the largest fields available: 40x40 cm for photons, and 25x25 cm for electrons. Profiles were measured on these linacs to investigate the inter-linac variations. **Results:** For the intra-linac variations, the energy tuning has the largest effect of 7% at 10 cm on beam penetration for small fields. Scattering in the field reduces this effect for larger fields. Wedged-field profiles are affected more than the open field, due to the dependence of transmission on energy. For inter-linac variation, profiles measured from three different machines vary more than 2% due to beam tuning differences, lateral displacement of flatteners or scattering foils, and differences in position of components relative to the source. **Conclusion:** The range of inter-linac and intra-linac variability has been measured on a Primus linac and is clinically significant. This data will be used with Monte Carlo treatment head simulation to calculate gold standard beam model benchmarks for the development of tunable beam models of high accuracy and detail in the dose-critical components of fluence.

SU-FF-T-294

Interference of I-125 Dose Distributions by Neighboring Seeds in Dense Packing Configurations: A Radiochromic Film Study

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Purpose: To study the interference effect on the I-125 seed dose distributions by neighboring seeds in dense packing configuration using radiochromic EBT film dosimetry. **Method and Materials:** Radiochromic EBT films (lot #35076) were used to measure the dose distributions around I-125 seed (Implant Sciences model 3500) with neighboring dummy seeds in dense packing configurations in solid water phantom. The types of dummy seeds studied included model 6714 (dummy of 6711), xenated dummies with and without sliver marker. Four dummy seeds of the same type were positioned parallel to the active seed, two on the left and two on the right, with center-to-center spacing of 1mm (B), 2mm (C) or 3mm (D). The single seed (A) configuration was also done for comparison. EBT films were located at contact geometry, 2mm or 5 mm distance from the plane of seed/s. After exposure, all the experimental and calibrations films were scanned using PeC CCD100 densitometer with 0.2mm spatial resolution. Conversion from optical density to dose was achieved based on the established calibration curve. The dose distributions for configurations B, C and D were compared with those of A. The ratios of B/A, C/A and D/A were also plotted against the radial distance from the active seed center. **Results:** Compared with configuration A, we found major dose reduction up to 80% in the contact film for configuration B. The extent of dose reduction was progressively less; but remains significant, for configurations C and D, and for 2mm and 5 mm distances. **Conclusion:** We have observed major dose reduction (up to 80%) around an I-125 seed with neighboring seeds in dense packing configurations. Such interference may be clinically significant for prostate implants and eye plaque treatment when the interseed distances are small. **Acknowledgement:** Implant Sciences Corporation, model 3500 I-125 seeds.

SU-FF-T-295

Intermediate Energy Photon Dramatically Improves Penumbra, Dose Distribution Homogeneity and Conformality for Small Field Radiosurgery

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Purpose: Stereotactic radiosurgery ensures highly conformal treatment of small volumes. When treating lesions with no microscopic extension and with efficient immobilisation, the PTV (Planned Target Volume) closely overlaps the GTV (Gross Tumour Volume). When using dedicated beam collimation devices, the radiological penumbra accounts for an additional 2 to 3mm dose gradient extending within the normal tissue. We hypothesized that, for small radiosurgery field sizes, intermediate energy photons (IEP, above orthovoltage and below megavoltage) will dramatically reduce the radiological penumbra. **Material and Methods:** Monte Carlo simulation was used to investigate the dose distribution characteristics and the radiological penumbra of monoenergetic photons (100 keV to 1 MeV) in a water phantom and for various field sizes (0.5x0.5 to 4x4cm^2). A virtual unit based on a simulated optimised IEP spectrum was described in the Pinnacle^3 TPS using an extended kernel library in the kilovoltage range. **Results:** Radiological penumbra below 300µm are generated for field sizes below 2x2 cm^2 at all depth and for monoenergetic photons between 200 to 400keV. The depth dose curve is steeper with a 50% relative dose at 6.5 cm depth, the dose homogeneity in the target is dramatically increased, and the dose to the bone is not increased. An 800 kV beam generated in a 0.5mm tungsten target maximizes the photon intensity in this range. Using six coincidental IEP generators allow a dose rate of 1.5Gy per minutes at 5 cm depth. Pinnacle^3 confirms the dramatic reduction in penumbra size, and the superiority of IEP over megavoltage beams for radiosurgery applications regarding dose distribution homogeneity and conformality. **Conclusions:** The reduction of radiological penumbra is linked to the reduced photon scattering using small field sizes and the reduced secondary electron range using IEP. This is the first report of the use of IEP for radiosurgery.

SU-FF-T-296

Inverse Treatment Planning Using Volume Sampling with Monte Carlo Dose Calculations

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Purpose: We investigated three methods of random sampling of voxels within regions of interest (ROI), using Monte Carlo dose calculations for inverse treatment planning. We studied their effects on file size, accuracy of dose volume histograms, computation time and accuracy in the objective function and determined the impact of number of simulation histories on the objective function. **Method and Materials:** A dose distribution, stored as double precision, of a clinical lung cancer plan was calculated using Monte Carlo simulation (NXEGS NumeriX, LLC). Only the dose in the ROI (excluding the external) is required, and is stored as integers. Three equations were tested to determine the number of sampling points within each ROI. The first was to keep the same relative percentage of volume for all ROIs. The second was proportional to the hyperbolic tangent of each ROI volume, while the third was proportional to the cube root of the volume. A least square objective function was calculated on all resulting sampling methods. **Results:** By saving dose values as integers instead of doubles, a 75% reduction is seen in file size, while keeping accuracy to 0.001%. The objective function computational efficiency improvement is directly proportional to the data storage reduction. A further reduction of 94% and 73% occurred when using the cube root and hyperbolic tan of the volume respectively, while producing a 0.03% and

1.8% difference in objective functions compared to that calculated with full ROI volumes.**Conclusion:** By sampling ROIs where the number of points is proportional to the hyperbolic tangent of the volume there was a savings of approximately 75% of data stored which directly translated into reduction in objective function computational time, with a 0.03% difference in objective function compared to that with full volume calculations.

SU-FF-T-297

Investigating Using IMRT Convert Parameter Settings to Improve the Agreement Between Planned and Delivered Dose Distributions

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Purpose: To improve the IMRT quality assurance process**. Method and Materials:** The linear accelerator used in this study was a Varian model 21EX with a 120 multi-leaf collimator**.** IMRT planning was conducted on an ADAC Pinnacle³, v6.2b, P³IMRT treatment planning system**.** Fluence measurements were analyzed using a MapCHECK™ unit consisting of 445 N-type diodes**.** Coplanar dose composites from thirty-two converted IMRT plans were analyzed using an ANOVA-TM v.3.0.0.2 software package**.** The software, containing design of experiments (DOE) techniques, utilizes analysis-of-variance methods and orthogonal array designs for conducting efficient experimentation**. Results:** From the ADAC Pinnacle³ convert parameters which were selected for this study, only the minimize tongue and groove parameter had a notable contribution toward influencing the percent agreement between the planned and the delivered dose distributions, (rho = 5.50%)**.** Statistically, the calculated value "rho" indicates a parameter's unique contribution toward changing the percent agreement; the bigger the rho, the bigger the parameter's contribution**.** Field size, which was considered to be an uncontrolled noise factor, was found to be a significant noise factor influencing the agreement output, (rho = 70.10%)**.** Beam energy, also an uncontrolled noise factor, was found to have a smaller contribution influencing the agreement output, (rho = 6.09%) **Conclusions:** Changing the convert parameters cannot be used to significantly improve the IMRT quality assurance process**.** While the convert parameters do affect treatment plan dosimetric results and delivery times, they will not significantly affect the outcome of the IMRT QA results**.** DOE techniques can be very useful when analyzing the contributions from experimental factors.

SU-FF-T-298

Investigation of Effects of Magnetron Replacement On a Helical Tomotherapy Unit

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Purpose: To quantitatively evaluate the physical effects of magnetron replacement on a Helical TomoTherapy system (TomoTherapy Inc., Madison, WI, USA) Methods and Materials**:** A Helical TomoTherapy (HT) (TomoTherapy Inc., Madison, WI, USA) is in clinical use at our institutions**.** Due to various design, engineering and manufacture issues, the magnetron (e2v Technologies, Essex, UK) used on HT system needs to be replaced some times during unit maintenance or repairing**.** The magnetron provides microwave power to LINAC accelerator and thus its output has direct effect on the LINAC beam quality and subsequent dosimetry characters**.** In this work, the effect of replacing a magnetron on HT system is investigated**.** A Tomo water tank, 8 channel Tomo-Electrometer and X1Sl ion chambers (Standard Imaging Inc., Middelton, WI, USA) are used to measure beam output, beam PDD curves and profiles before and after the magnetron replacement**. Results:** The central axis output of the machine is found to be about 2% lower compared to measurement before magnetron replacement**.** Both transverse and longitudinal beam profiles at various depths are found to be in a very good agreement before and after magnetron replacement, as was the central axis percentage depth (PDD) curves for various available jaw sizes (5 cm, 2.5 cm and 1 cm)**. Conclusions:** Magnetron is a major part of a LINAC system and its replacement should be checked carefully**.** In this study, a series of measurements are performed to compare the machine beam properties before and after magnetron change**.** It is shown that the central axis output changes about 2%, and no significant change is found on beam profiles and PDDs before and after magnetron replacement.

SU-FF-T-299

Investigation of Near Surface Doses in Mesothelioma Intensity Modulated Radiation Therapy

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Purpose: To investigate the measured and computed near surface doses for intensity modulated radiation therapy (IMRT) of mesothelioma**.** The near surface dose value is important since in most cases the intent is to deliver about 90% of the prescribed dose to the surgical scar region. **Material and Methods:** Two planning CT scans (3mm slice thickness) of a humanoid Alderson phantom with 5 mm and 10 mm bolus placed on the thoracic region were acquired with our Philips CT scanner**.** At the time of CT, opaque markers are placed under bolus to designate 10 different locations throughout thoracic region for calculations and measurements**.** IMRT plans are generated using the Nucletron OTP treatment planning system**.** IMRT calculations are performed for a 3 mm × 3 mm calculation grid and inhomogeneity correction with pencil beam algorithm**.** Plans are delivered to the phantom with a Siemens Oncor linac**.** Doses are measured at each marked location under each bolus, mimicking depths of 5 mm and 10 mm, using a pair of LiF thermoluminescence dosimeters (TLD). **Results:** The average dose difference between the measured and calculated data at depth of 5 mm is 8.6% with percent differences ranging from 3.6% to 18.3%**.** For the points at 10 mm depth this average is about 2.7 % and the percent difference range is 0.1% to 4.7%**. Conclusion:** Our results indicate that dose calculated for mesothelomia IMRT cases at depth of 5mm show a larger uncertainty relative to the measurements than dose calculated at deeper depth of 10 mm for OTP**.** The measurements show good agreement at 10 mm depth; on average, results are within accuracy of the TLD measurements (within 3%)**.** It is therefore important for patient treatment to carefully evaluate the near surface dose (i.e.5 mm depth) via measurements**.**

SU-FF-T-300

Investigation of Respiratory Motion Effect On Lung Tumor Radiotherapy Using 4D Monte Carlo Treatment Planning and 4D CT

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Purpose: To investigate the respiratory motion effect on lung tumor radiotherapy using 4D Monte Carlo treatment planning and 4D CT**. Method and Materials:** 4D CT images for four lung patients (two upper lung tumors and two lower ones, with different volumes) were acquired by using a GE LightSpeed-QX/I scanner**.** Ten phase bins were used in the 4D-data acquisition**.** A 4D Monte Carlo treatment planning system based on the EGS4/MCDOSE code was developed to calculate the 3D dose and map the 3D dose of the CT at each phase to the inhale CT (as reference)**.** CT images at different phases were registered with the inhale CT image using a BSpline deformable registration model**.** Isodose lines and the DVHs of tumor and normal lung were used to compare the 4D plan (3D dose mapped from the CT at 10 selected phases to the inhale CT) and the 3D reference plan (3D dose for the inhale CT) for each patient**.** Respiratory motion effect was investigated for the different tumor volumes and locations**. Results:** In our study, for the upper lung tumors, the respiratory motion effect on target dose coverage was insignificant (<2% difference between the 4D plan and the 3D reference plan)**.** However, for the lower lung tumors, the motion effect was clinically significant (>3% difference between the 4D and 3D plans)**.** For the same PTV margin, less motion effect was observed for larger tumor volumes**.** The motion effect for the normal lung volume receiving dose was not correlated with the tumor volume or the location**. Conclusion:** Respiration motion may significantly influence the tumor dose in lung radiotherapy and 4D dose calculation may be necessary when treating tumors in the lower lung or when the tumor volume is small

SU-FF-T-301

Investigation Of The Accuracy Drift For The CyberKnife Systems

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Purpose: During a routine quality assurance check, it was found that the total accuracy was drifted out, or deteriorated to 3.5mm and greatly exceeds the manufacturer's specification of less than 1mm**.** In this report,

observations and the preliminary results of investigation on the issue will be presented. Lessons learnt from the incident, suggestions and precaution measures to prevent from its happening will also be discussed. **Method and Materials:** Previous records of the routine QA and system logs were carefully reviewed. All evidence and all likely cause for the drift, such as the imaging system out of calibration, physical contacts, earthquakes, hospital vibration and room settling were thoroughly examined. Personnel who have access to the CyberKnife Systems were interviewed. **Results:** The imaging system required no adjustment or recalibration. The system log files seam not corrupted. The robot appeared to be off from its original position. Two spots, one dent and one scratch, on the linac cover occurred over two years ago and were excluded from the likely cause list. The accuracy was re-confirmed within the specification by end-to-end tests after several adjustments, including the robot re-mastering and the secondary calibration of the treatment paths. The likely causes suggested by the manufacturer were not very convincing. **Conclusion:** By nature, any mechanical system can fail at any time. Failure to identify the true cause of the problem could result in its happening again at any time no matter how often QA is performed and could potentially expose patients to great risks. Rigorous QA such as the end-to-end should be performed monthly; the iso-post test should be performed daily and the laser spot at the perch position should be performed prior to each patient treatment. Some kind of interlock systems should be developed to self-check or detect any deviation for each subsystem.

SU-FF-T-302

Investigation of the Effects of Approximations in Gamma Knife Stereotactic Radiosurgery Planning

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Purpose: GammaPlan, the planning software for Gamma Knife stereotactic radiosurgery, approximates many parameters to increase calculation speeds. These approximations can introduce dosimetric errors. We investigate the magnitude of these errors. **Method and Materials:** A planning algorithm was written to avoid the use of approximations. Skull scaling is accomplished through a simple edge detection algorithm on the imported images. Dose calculations are accomplished through the use of TMR measurements and beam profiles taken at various depths, and of all collimators. To measure the TMR of one beamlet, 200 of the 201 sources were plugged. A tungsten sphere was designed to provide additional attenuation of unwanted beamlets when taking film and ion chamber measurements in its center. Ion chamber measurements are obtained for various amounts of water-equivalent ABS plastic for the 14 and 18 mm collimator. Additionally, Gafchromic film is placed between the pieces of plastic to obtain both PDD and TMR measurements of all collimators. The Gamma Knife calibration sphere was then modeled in both GammaPlan and our algorithm, and treatment times for isocenters placed throughout the sphere were calculated using both algorithms. **Results:** The 18 mm collimator TMR showed small deviations past 40 mm from the 0x0 curve used by GammaPlan, and differences up to 2% are seen at shallow depths. The 14 mm collimator showed similar behavior. Discrepancies of 3.8% on average (maximum 8.9%) were calculated for shots placed in various locations throughout the calibration sphere. Differences increased with the distance from the middle of the sphere and increasing gamma angle. **Conclusion:** We developed a robust Gamma Knife planning software, effectively reducing errors due to approximations. Our results agree with GammaPlan's calculated times. Skull scaling differences are the major source of the discrepancies between the two calculations.

SU-FF-T-303

Ion Loss Measurements for a Large-Volume Free-Air Ionization Chamber

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Purpose: To extend the capabilities of large-volume ionization chambers to higher-fluence sources by thoroughly evaluating ion loss in preparation for Electronic Brachytherapy air-kerma strength measurements. **Method and Materials:** Electronic Brachytherapy was recently approved by the FDA as a low-energy photon-emitting source for the treatment of breast tumor cavities after lumpectomy surgery. The dosimetry for these types of treatments is based on well-established AAPM TG 43 protocols for low-energy photon-emitting brachytherapy sources. This task group recommends that source strength for low-energy brachytherapy sources be measured with a large-volume free-air ionization chamber to determine the air-kerma rate absolutely. Until now, using such a chamber for Electronic Brachytherapy sources has not been possible because of the higher x-ray energies of Electronic Brachytherapy sources (up to 50 keV) as well as their significantly greater exposure rates. There is convincing evidence that the air-kerma strength of Electronic Brachytherapy sources may be measured with the Variable-Aperture Free-Air Chamber (VAFAC). To this end, a systematic investigation of the mechanisms of ion loss has been completed by varying exposure rates, plate separations, and high-voltage biases. **Results:** Measurements of ion-loss agreed with empirical predictions to within 0.2% using the VAFAC for low-energy photon-emitting brachytherapy sources with strengths up to 5000 U, more than 50 times higher than the upper limit of the current U.S. national standard (100 U), and within the estimated source strength of new Electronic Brachytherapy sources. Measurements of two coefficients for conventional ion-loss equations are $\Gamma_o^2=5.40\text{x}10^{13}V^2A^{-1}m^{-1}$ and $E_1=6.0Vm^{-1}$, which are within the range of values published in the literature. **Conclusion:** The VAFAC's measurement capabilities have been extended to higher-fluence sources (up to 5000 U) in preparation for air-kerma strength measurements of Electronic Brachytherapy sources. Measurements of empirical coefficients are within the range of values listed in the literature.

SU-FF-T-304

Is 0.5 Cm Leaf Width of MLC Beneficial in IMRT?

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Purpose: Evaluate treatment plan quality and quantify dosimetric accuracy of IMRT for different disease sites with MLC of 0.5 and 1.0 cm leaf width. **Method and Materials:** We tested a hypothesis, quality of IMRT treatment plans with smaller MLC leaf width is better, by developing treatment plans on Pinnacle treatment planning system (TPS) for multiple patients (total 60) with tumor sites located in Head and Neck (H&N), Vertebral Body and Prostate. For each patient, two plans are created using same objective functions and optimization parameters and algorithm (Direct Machine Parameter Optimization): one with 0.5 cm leaf width; the other with 1.0 cm leaf width. The TPS beam modeling of the two virtual machines was exactly the same except for the MLC leaf width. The dose volume histogram (DVH) is used in the evaluations of plan quality. All target coverage is normalized to the criteria of 95% of the target volume receiving prescribed dose. A diode array (Mapcheck) was used to quantify the dosimetric accuracy of all plans created with two MLC leaf width resolutions. **Results:** DVHs of all the patient plans reveal very minor dosimetric differences between the IMRT plans of the two MLC systems for the same patient. There are almost identical target coverage and similar dose distributions among the critical structures in H&N patients and vertebra body patients. For prostate, plan of 1 cm MLC leaf width has slightly more hot spots in the target with the same dose coverage criteria. Planar doses comparisons with Mapcheck measurements indicate slightly larger uncertainty in 0.5 cm leaf plans. **Conclusion:** There are negligible dosimetric differences in IMRT plans created with 0.5 cm and 1.0 cm leaf width resolution. However, the dosimetric accuracy of plans generated with 1.0 cm leaf width is better than the plans generated with 0.5 cm leaf width.

SU-FF-T-305

Is It Necessary to Adjust the Prescription Dose to Compensate for Cobalt Source Decay of Gamma Knife Radiosurgery?

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Purpose: To investigate whether it is necessary to adjust the prescription dose to compensate for Cobalt source decay of Gamma Knife radiosurgery (GKRS) for trigeminal neuralgia. **Methods and Materials:** A radiobiological model for GKRS was utilized to estimate the radiation response of the brain tissue to the radiosurgery dose distributions expressed in the form of dose volume histogram (DVH). For each bin of the DVH, a linear-quadratic equation was constructed to calculate the Extrapolated Response Dose (ERD) given the specific dose rate and dose. The relationship between ERD and clinical outcome, i.e., pain relief of trigeminal neuralgia, was evaluated using the data from 343 patients who

received trigeminal neuralgia GKRS during a period of 6 years. This model is validated by published clinical data. Necessary dose adjustment to compensate for source decay was obtained during a period of 10 years (two half-lives). **Results:** Between the first (5/98-5/99) and last (11/01-11/03) quartile of the patients, complete or nearly complete (≥90%) pain relief rate was 54.2% verse 50.6%, respectively, at the 12 month follow-up. Dose rate was not a factor influencing pain relief (p=0.755). Meanwhile, our model predicts that pain relief rate drops 3%, and the necessary dose adjustment for the trigeminal neuralgia GKRS should increase 3-5% for the typical prescription dose of 70-90Gy at the end of two half-lives. The model also suggests that when the radiosurgery prescription dose is low (e.g. cases such as acoustic neuroma or brain metastases) dose adjustment is not necessary because the change of ERD is negligible. **Conclusions:** Prolonged treatment due to radiation source decay has little effect on clinical outcome for trigeminal neuralgia GKRS with up to 10 years of service.

SU-FF-T-306

Is It Safe to Switch Patients Between Different Linacs

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Purpose: Due to the limited machine availability, a clinical decision has to be made as whether a patient can be treated on a different machine of the same nominal energies. This work investigates the feasibility of switching patients between machines for IMRT. **Method and Materials:** We have performed Monte Carlo simulations of photon beam from different models and different vendors' clinical accelerators. Treatment plans of Siemens Primus, Primart and Varian-21Ex accelerators and tumor sizes are studied including prostate and head and neck tumors. We have compared the maximum, minimum and mean dose to the target and to the critical structures, and the tumor-control-probability to determine the possibility to switch a patient or cancel the treatment. **Results:** In FCCC, three attuned Primus linacs can be used one set of beam data for commissioning the treatment planning systems, while Primart and two Varain-21Ex linacs have different beam data. Our results show that the two Siemens machine models share similar features. The dose difference at the minimum dose point for Primus is 2% higher than Primart. Owing to a larger beam penumbra for Varian machines, it appeared a cold spot at the target, but more volume at higher dosages to the surrounding structures. To reduce the cold spot, a factor of 1.042 can be used to increase the MUs. The TCP results show that treating a patient with slightly less accurate dose is generally better than canceling the treatment. **Conclusions:** Patients can be safely treated using same nominal energy photon beams on linacs of the same model and vendor; small differences are found between different vendors, which may be compensated by adjusting MUs to ensure target coverage. It is generally more therapeutically beneficial to switch a patient to a different machine than to cancel a treatment.

SU-FF-T-307

Is PTV Coverage a Valid Indicator for Plan Evaluation in Shallow Tumor Cases Where the PTV Extends Into the Build-Up Region?

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Purpose: The Planning Target Volume (PTV) is defined by ICRU report 50 as a geometrical concept, used to select appropriate beam sizes and beam arrangements. Clinically, a plan is normally acceptable if the 95% isodose surface covers the PTV. The goal of this study is to investigate the validity of using the PTV coverage for plan evaluation in shallow tumors where the PTV extends into build-up region. **Method and Materials:** A conventional 3-D conformal technique with a 10mm CTV-PTV margin was used to produce 3-field plans for a deep tumor (Prostate) and a shallow tumor (Head&Neck). For the H&N case, as the CTV is normally at a fixed distance below the skin, the geometric uncertainties are mainly from patient-beam positioning errors. The CTV coverage with these errors was assessed by shifting the isocenter to 200 separate positions. The isocenter offsets were randomly selected using 3 uniform random Cartesian deviations between -10mm and 10mm, with a 3D distance constraint of 10mm. For the shallow tumor case, another plan with a 5mm larger field was made. The DVH of each plan with 200 shifted isocenters was analyzed. **Results:** In the H&N case, an "unacceptable plan" was obtained, which has V95=81% for the PTV. In the prostate case, we obtained an acceptable plan which has V95=94.9% for the PTV. However, both cases gave the same good CTV coverage for 200 shifted isocenter plans. For the H&N case, PTV coverage (V95) can be improved (from 81% to 83%) by increasing field sizes, but without improvement in CTV coverage, and larger fields increase skin dose. **Conclusion:** The current method of evaluating plan quality by means of PTV coverage is adequate for deep tumors, but is not adequate for shallow tumors. A new indicator for CTV coverage evaluation in shallow tumor cases needs to be developed.

SU-FF-T-308

ITC Assists Developers of ATC Compliant DICOM Export for Clinical Trials

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Purpose: The Image-guided Therapy QA Center (ITC) as part of the Advanced Technology QA Consortium (ATC) has played a key role in assisting treatment planning system (TPS) developers in verifying that their DICOM implementations (CT, RT Structure Set, RT Dose, RT Plan, and RT Image) match ATC's conformance statement. This presentation will review lessons learned in this important effort. Methods and Materials: ITC hosted a series of DICOM Implementers' Workshops to assist TPS vendors in implementing RT objects needed for clinical trials. A system of software ("ATC Method 1") developed at ITC to receive, process, and review volumetric treatment planning data for advanced technology clinical trials was used to assist vendors in their implementation of DICOM export. ATC's DICOM conformance statement specifies requirements for using DICOM RT objects in these clinical trials. ITC's DICOM fileset reader converts incoming data to an internal format for efficient display and review using the ITC web-based Remote Review Tool (RRT). The RRT was used by TPS developers to visualize/compare submitted images, structure sets, and dose distributions, thus greatly facilitating their DICOM implementations. **Results:** Interactions with developers have exposed several problems in interpretation and implementation of the DICOM standard resulting from the complexity of DICOM RT objects and differences in design/capabilities of TPSs. Examples of problems seen include CT/Structure/Dose miss-registration and DVH-calculation discrepancies. To date, 6 TPSs have released ATC-compliant DICOM export software. ITC has received DICOM data matching the ATC conformance statement from a total of 15 TPSs. ITC has worked with 8 additional TPS developers. **Conclusions:** The ITC web-based Remote Review Tool has proven to be of great help to vendors in developing and verifying implementations. More effort is needed by vendors to make digital data submission for clinical trials a simpler process. Support: NIH U24 CA81647

SU-FF-T-309

Laser-Accelerated Proton Therapy: Target Chamber Design and Shielding Requirements

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Purpose: Recent advances in laser technology have facilitated proton (light ion) acceleration using laser-induced plasmas. In this work, we investigate target chamber designs and their shielding requirements for a laser-proton therapy system. **Method and Materials:** This new therapy system employs laser-accelerated protons. If successfully developed, it may provide a compact and cost-effective solution to energy- and intensity-modulated proton therapy (EIMPT). Since laser-accelerated protons have broad energy and angular distributions, which are not suitable for radiotherapy applications directly, we have designed a compact particle selection and beam collimating system for EIMPT beam delivery. The target chamber contains the laser focusing and target assembles and is connected to the proton beam collimation and particle selection device. Monte Carlo simulations using MCNPX and FLUKA have been performed to verify the shielding walls for the experimental setup, which consist of stainless steel, polystyrene and lead. **Results:** The primary particles resulting from the laser-target interaction are protons and electrons. Our particle in cell simulation predicted energy spectra with 300 MeV

maximum energy for protons and 20 MeV for electrons for a laser intensity of 10^{21} W/cm^2. The maximum number was 10^{11} and 10^{12} per pulse for protons and electron, respectively. Our Monte Carlo simulations showed that a combination of 1/4" 304 stainless steel, 6" polystyrene and 3" lead will reduce the combined leakage dose equivalent to 0.32 μSv (0.032 mrem) per laser pulse at 1 m from the chamber, which included the effect of all primary and secondary particles. **Conclusion:** We have designed an experimental setup to accommodate the laser focusing mirror, the target assemblies, the beam collimator and the particle selection system. Different shielding walls are designed to ensure the leakage dose equivalent to within 20 μSv (2 mrem)/week.

SU-FF-T-310

LINAC Dosimetry: Benchmark Data Set Requirements

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Purpose: Provide accurate basic acceptance data needed for modeling dose calculation algorithms. Provide accurate dosimetry data for special geometries and heterogeneities that are frequently encountered in IMRT planning systems. **Method and Materials:** Develop requirements for the Benchmark Datasets that fully characterize the modern day delivery systems in commercially available 3D treatment planning systems (TPS), consistent with TG-53 report on TPS QA. The hypothesis is that high quality benchmark data can be acquired by comprehensively characterizing single linacs of each make. The RPC database was used to demonstrate that hypothesis. **Results:** A measurement template that defines basic data for beam shape, penumbra, and radiation dosimetry characteristics, such as depth dose and scatter factors, has been defined for LINACs from the three major manufacturers: Elekta, Siemens, and Varian. Measurements will be made on a Varian Clinac 21EX, a Siemens Oncor and an Elekta Precise. The x-ray beam energies measured will be 6, 10 and 18 MV. These measurements will be made in a 3D water phantom scanning system, using detectors that will enable high spatial resolution of dose gradients resulting from beam limiters. These detectors will include small volume ion chambers, diodes, and film. In addition, radiation dose in and around various heterogeneities will be measured in a water-equivalent solid phantom that will allow the insertion of heterogeneous components. A comprehensive measurement uncertainty analysis will complement the data. Software has been developed for importing the Benchmark Data into structured database following the TG11 format. **Conclusion:** Software to streamline routine TPS QA, using the benchmark data, will be made commercially available, enabling recommendations from TG53. **Conflict of Interest:** This project has been funded in part with Federal funds from the National Cancer Institute, National Institutes of Health, Department of Health and Human Services, under Contract No, HHSN261200522014C and by Sun Nuclear Corporation.

SU-FF-T-311

LINAC Dosimetry: Benchmark Data Set Uncertainty

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Purpose: Determine sources of error in the collection of a Benchmark Data set for LINAC dosimetry and provide methods of error correction that will ensure the highest possible accuracy of the dosimetric data. **Method and Materials:** Guided by the measurement requirements for the Benchmark Datasets, the sources of experimental error can be divided into 3 sources: 1) discretization and volume averaging errors; 2) Stochastic errors; and 3) Systematic or artifactual errors. Measurements will be made in a 3D water phantom scanning system and in a water-equivalent solid phantom that will allow the insertion of heterogeneous components. **Results:** We present theoretical analyses of the expected errors associated with ion chamber, radiochromic film, and diode measurements and provide specific techniques that will enable high spatial resolution of dose gradients resulting from beam limiters and dose perturbations in and around heterogeneity interfaces, such as air/tissue, lung/tissue, bone/tissue. These techniques include de-convolution of chamber response and a 3D correction matrix of a film scanner. **Conclusion:** Theoretical limits of spatial resolution in LINAC dosimetry are achievable and demonstrable using dosimetric tools available today. These tools and methods will be used to collect accurate Benchmark Dosimetry data for future research in Monte Carlo techniques for treatment planning as well as automated software tools that will enable systematic QA of modern treatment planning systems. **Conflict of Interest:** This project has been funded in part with Federal funds from the National Cancer Institute, National Institutes of Health, Department of Health and Human Services, under Contract No, HHSN261200522014C, NCI grants R01-CA-100636, and by Sun Nuclear Corporation.

SU-FF-T-312

Liquid Helium Calorimeter for Brachytherapy Source Strength Measurement

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Purpose: To construct and demonstrate the utility of a new liquid helium calorimeter for the determination of contained and emitted power of low dose rate (LDR) and beta emitting brachytherapy sources **Method and Materials:** A liquid helium adaptation of the UWMRRC Stump calorimeter (Rev. Sci. Instrum., 76, 2005) was constructed for use with LDR and beta emitting encapsulated brachytherapy sources. Silver absorber construction provides 4π measurement geometry for contained power measurements, eliminating the need for geometric or solid-angle corrections and removing uncertainty stemming from source anisotropy. Temperature of the absorbers as well as the detector housing is actively controlled, and an electrical substitution measurement technique is used. This technique does not require corrections for thermal coefficients that change with temperature, thus eliminating the uncertainty of the absorber mass from the measurement uncertainty. Temperature is monitored using germanium resistance thermometers, and overall system temperature stability is improved by placing the liquid helium reservoir inside a vacuum chamber that is in turn surrounded by liquid nitrogen. **Results:** The decreased noise floor of the liquid helium calorimeter will permit more accurate measurements of low activity sources than was possible with the Stump calorimeter. Preliminary MCNP5 Monte Carlo modeling indicates that the contained power collectors will be 99.99% efficient for the LDR sources for which the calorimeter was designed, and that for the ^{90}Sr/^{90}Y beta emitting source, the efficiency decreases to 98.13% as a result of the more energetic bremsstrahlung photons. **Conclusion:** Knowledge of the contained and emitted power for brachytherapy sources can yield a direct source strength value for use as a benchmark in Monte Carlo statistical models. The emitted fraction, which is the quotient of the emitted power and the total contained power, can also be utilized in determining the validity of geometric and atomic source composition used in statistical models.

SU-FF-T-313

Low Energy Experimental Elastic Cross Sections for Medical Physics Application

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Purpose: Elastic cross sections for electron energies below 10 MeV are fundamental quantities needed in treatment planning systems used at hospitals and health facilities. To date, there is very little if not no data within that energy regime. **Method and Materials:** In collaboration with the high current, high energy resolution continuous electron beam of the Department of Energy's Jefferson Lab accelerator, we have performed a first stage of dedicated experiments with energies of 100-150 keV to collect data for this type of reactions. The targets used were gold, copper and silver. A Mott scattering chamber was used to detect the outgoing electrons. **Results:** We will present the first results of this program that aims at performing a wide range of measurements including the use of polarization data for spin studies. **Conclusion:** This research will provide much needed electron cross section data in the 100-150 keV range for treatment planning, dose calculation, and development of mono energetic Brachytherapy sources. The effects of polarization on cancer cell response will also be studied.

SU-FF-T-314

Macro Monte Carlo Simulation of Visible Light Transport in Heterogeneous Media

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Purpose: Although Monte Carlo (MC) simulation has become the gold standard in the transport of visible and near infra-red photons in turbid media such as tissue, its computational intensity limits its practical application. To increase the computational efficiency of visible MC, we have adapted a macro-Monte Carlo (MMC) method (Neuenschwander, *et al.* 1995, Phys. Med. Biol. **40**, 543-574) to the modeling of light transport in heterogeneous media. **Method and Materials:** Traditional MC routines trace individual photons step-by-step through the tissue. Instead, the MMC approach relies on a data set consisting of spheres or 'kugels' in which the light absorbed in each voxel is pre-calculated using a traditional MC routine. At each MMC step, the pre-calculated absorbed light dose in the appropriate sphere, aligned to the current position and direction of the sphere, is recorded in the dose matrix. The position and direction of the photon exiting the sphere are chosen from the exit distribution of the pre-calculated sphere, and the process is repeated. By choosing the size of the pre-calculated sphere appropriately, arbitrarily complex boundary geometries can be simulated. To allow the simulation to remain accurate arbitrarily close to boundaries, we have it automatically switch to photon-by-photon MC for points less than one kugel radius. **Results:** We compare the accuracy and calculation time of the MMC method with a traditional MC algorithm for a variety of tissue optical properties and geometries. We find that the MMC algorithm can increase the speed of calculation by as much as two orders of magnitude, depending on the optical properties and geometry being simulated, without a significant loss in accuracy. **Conclusions:** The drastic improvement in efficiency accomplished by implementing the Macro Monte Carlo algorithm for visible photons makes it fast enough to be potentially useful in photodynamic therapy treatment planning and optical measurement analysis.

SU-FF-T-315

Mammosite Balloon Type Vs. Integral Dose to the Skin

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Purpose: The purpose of this study was to investigate the influence of different Mammosite applicators (Spherical vs. Ellipsoidal) on integral dose to the skin. **Introduction:** In early 2005, Mammosite introduced a new balloon in ellipsoidal shape. Ellipsoidal balloon has typical five dwell positions with 10 mm dwell spacing, and different weightings to each dwell position compared to the single dwell position for spherical balloon. The dose prescription for both balloons is identical. However, the influence of different dwell positions & dwell time on integral dose to the skin is not well documented. Dose distributions were reviewed retroactively in 12 mammosite cases to establish the relationship for integral dose to skin vs. balloon type. **Methods and Materials:** Dosimetry plans (*Nucletron, V14.26) for twelve mammosite patients were reviewed. Nine patients were treated with spherical balloon and remaining three patients received treatment with ellipsoidal balloon. The dose prescription, for all the patients was 34 Gy in 10 fractions at 10 mm from balloon surface. In order to eliminate the influence of skin distance from the balloon center on integral dose, each plan was re-run using both types of dwell configurations. Entire skin surface (thickness 5 mm) above the balloon was contoured. Dose volume histograms (DVH) were generated for the skin. **Results:** The DVH analysis indicated consistently higher skin dose with Ellipsoidal balloon compared to the spherical balloon technique. The difference was more pronounced for shorter skin distance (7-10 mm) from the balloon surface. On average the integral skin dose was higher by 11% with ellipsoidal balloon for skin distance of $\geq$ 7 mm. While for skin distance of $\geq$ 13mm, the integral dose was higher by 6.5% for ellipsoidal balloon. **Conclusions:** Ellipsoidal balloon technique of mammosite delivers higher integral skin dose. It is too early to indicate any clinical significance of these findings.

SU-FF-T-316

Measured and Calculated Dose Distribution Around 125I Brachytherapy Seeds in a Breast Phantom

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Purpose: To compare measurement with Gafchromic® EBT films and Monte Carlo (MC) calculations of the dose distribution around LDR brachytherapy ^{125}I seeds in a breast phantom and to analyze the effect of tissue elemental composition. **Method:** MC simulations of IBt Interseed^{125} seeds were performed, using MCNP4C. In view of the low energy of the photons, the detailed physics treatment was used, with libraries from EPDL97 and no electron transport. In order to evaluate the perturbation of the film, simulations were carried out to compare the dose distributions in the film and in water or acrylic. The radial dose function of tissues and potential substitutes were determined using MC and compared to associate the best substitute to the desired tissue. Measurements for 5 seeds in an acrylic breast phantom were performed and compared with the MC simulations for the same geometry. **Results:** Our simulations show no significant differences between dose distributions calculated in films and in water (average difference 0.13%). Similar results can be observed for simulations in acrylic. The radial dose function of acrylic is very close to the one of breast tissue (2/3 mammal gland, 1/3 fat). However, there is a significant difference in the dose distributions in acrylic and water (average 7%, maximum 25%). The comparison between the measurements in the acrylic phantom and the calculations shows a good agreement between the isodose distributions (within 12%). **Conclusion:** Both in water and in acrylic, EBT films appear to introduce no significant perturbation to the measured dose distribution around ^{125}I LDR brachytherapy seeds. These films are very useful tools for measurements around ^{125}I seeds. There is a significant tissue composition effect that should be taken into account in LDR brachytherapy dosimetry. Acrylic appears to be the best substitute for breast tissue. Seeds furnished by IBt.

SU-FF-T-317

Measured and Simulated Non-Target Whole-Body Doses for Selected IMRT and 3D-CRT Treatment Plans

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Purpose: A symposium at this year's APPM Summer Meeting calls for the attention to the non-target exposures during emerging modalities. The change from 3D-CRT to IMRT has been accompanied by many new challenges including a potential for an increase in second malignancies due to more fields and longer exposure times. The goal of this study is to establish a robust method for comparing in-phantom measurements and Monte Carlo simulations of whole body doses resulting from 3D-CRT and IMRT treatment plans. **Method and Materials:** Measurements using a RANDO phantom and MOSFET dosimeters were re-constructed to determine organ doses from three typical treatment plans, 4-field 3D-CRT, 6-Field 3D-CRT, and 7-Field IMRT for the prostate. Dose tally estimates using a segmented RANDO computational phantom were generated by MCNP5 and compared with experimental data. **Results:** The dosimeter readings show that the doses decrease as distances increase for all treatment plans. At 40 cm from the target, doses are reduced nearly 100%. At this location, the IMRT plan resulted in a dose that is a factor of 3-5 times higher than the two 3D-CRT plans. This is due to increase scattered radiation from the extended exposure time for IMRT treatment. Comparisons of organ doses will be done with ongoing studies of MCNP5 simulations for the above treatment plans.**Conclusion:** A method has been developed and tested to use MOSFET dosimeters to measure whole-body doses resulting from IMRT and 3D-CRT treatment plans. The case study for prostate shows that IMRT delivers higher out-of-field photon doses than 3D-CRT. By combining the Monte Carlo simulation of various accelerators and patient anatomy, the potential non-target doses can be better assessed than what is currently done, thus offering a practical way for the management of secondary exposures from emerging modalities.

SU-FF-T-318

Measured Versus Calculated Dynamic Wedge Dose Distribution Using Anisotropic Analytic Algorithm (AAA) and Pencil Beam Convolution (PBC) Algorithms

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Purpose: The purpose of this work is to compare measured and calculated 2D EDW dose distributions using AAA and PBC calculations algorithms. **Method and Materials:** A 6MV photon beam from a Clinac 2300C/D Linac equipped with 7 EDW was used. Dose distributions were calculated for square symmetric fields by a Varian Eclipse v7.3.1 3DTPS with AAA and PBC algorithms. EDW were commissioning in the TPS. Dose distributions were measured using Kodak EDR2 films in a perpendicular configuration at 5cm depth in a solid water phantom for 4x4, 10x10, 15x15 and 20x20 cm field size settings. TPS calculations were performed for the same conditions as measurements, using a phantom with the same geometry. Calculation grid was 2.5x2.5 mm for PBC and 1x1 mm for AAA. Dose distributions were compared using RIT v4.3 software with gamma evaluation using 3% dose variation and 3mm DTA criteria. **Results:** Measured versus calculated percentage depth doses and wedge factors agree within 1%. Profiles in the non wedged direction, exhibit variations lower than 2% of dose or 2 mm DTA. In wedged direction both algorithms reproduces the measured profiles with deviations smaller than 2% of the normalization dose except in the penumbra region. AAA algorithm models better the penumbra region. EDW with angle lower than 45º, both algorithms model the distributions within the acceptance criteria. Some differences could be seen in the corners of the beams. For EDW with 60º angle, the percentage of pixels that not passes the acceptance criteria using AAA is acceptable, but using the PBC algorithm the percentage must be considered (reaching 28.5% of the distribution), representing regions of disagreement that may be of clinical interest. **Conclusions:** AAA algorithm models EDW dose distributions better than PBC. Differences between both algorithms increase with field size.

SU-FF-T-319

Measurement of Neutron Background in Electron Beams From a Dedicated IORT Linear Accelerator and a Conventional Linear Accelerator

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Purpose: To measure the neutron background for an electron-only (IORT) and a conventional linear accelerator. **Methods & Materials:** A Siemens Mevatron ME [6 (not used), 9, 12, 15 and 18 MeV] and several Varian Clinacs [6 (not used), 9, 12, 16 and 20 MeV] were used in this study. Bubble (Type BD-PND; BTI Bubble Technology Industries) and track-etch detectors (TE) (Luxel+, Ja; Landauer) were used in these experiments. The detectors were placed at 1m from the target at azimuthal angles of 0°, 45°, 90°, 135° and 180°. **Results:** For conventional electrons at 0° the neutron leakages (Sv/Gy) are: $2x10^{-5}$ at 12 MeV, $1.0x10^{-4}$ at 16 MeV and $4x10^{-4}$ at 20 MeV. For angles >0°, the leakage is almost angle independent [$2x10^{-6}$ at 12 MeV; $(0.5\text{-}2)x10^{-5}$ at 16 MeV and $(2\text{-}4)x10^{-5}$ at 20 MeV]. For the ME, the neutron leakage was lower than for the conventional linac and also independent of angle for angles >0° {[0°: $6x10^{-6}$ at 12 MeV; $2x10^{-5}$ at 15 MeV; $5x10^{-5}$ at 18 MeV]; [other angles: $(2\text{-}5)x10^{-7}$ at 12 MeV; $(0.7\text{-}1.0)x10^{-6}$ at 15 MeV; $(2\text{-}4)x10^{-6}$ at 18 MeV]}. Using the upper limit of $5x10^{-7}$ Sv/Gy at 12 MeV for angles >0° and assuming a workload of 200Gy/wk and an inverse square factor of 10, the neutron dose is 0.01 mSv/wk. For the primary beam at 12 MeV, the 10x higher dose is compensated by the attenuation in the primary beamstopper[†]. **Conclusions:** Measurements have been made of the neutron leakage from an IORT machine and a conventional linear accelerator. The results show that the IORT has a leakage well below that of the conventional machine and that at 12 MeV for the IORT machine, the leakage is sufficiently low at all angles as not to be a regulatory problem. [†] G. Loi. et. al. Phys. Med. Biol. 51:695-702;2006

SU-FF-T-320

Measurement of Surface and Exit Dose in Megavoltage X-Ray Beams Using Micro-MOSFET Detectors

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Purpose: Knowledge of entrance and exit dose, specifically in breast cancers, is of significant clinical importance. New micro-MOSFET (Thomson & Nielsen Electronics Ltd., Ottawa, Canada) detectors offer an efficient means to accomplish this task. In this study we investigate the use of MOSFETs to measure surface and exit dose in external photon beams. **Method and Materials:** Ratios of measurements at the surface and a depth of d_{max} in a solid water phantom were correlated with Monte Carlo (BEAM) generated percentage depth dose curves to determine the water-equivalent thickness of the micro-MOSFET detectors. This was done for 6 and 18 MV x-rays in a 10x10 cm^2 field, both normally and obliquely incident. Exit dose was measured similarly and equivalent thickness determined. **Results:** Correlation of the predicted depth dose and measured ratios indicates a water-equivalent thickness of 0.8-1.0 mm for the micro-MOSFET at the surface. All results indicate that the equivalent thickness is independent of angle of incidence and energy. The same detectors show an equivalent thickness that is approximately 0.4 mm and energy independent when measuring exit dose. We anticipate final results to include additional measurements at 10 MV and a field size of 40x40 cm^2. **Conclusions:** This work indicates micro-MOSFET detectors are a reliable (reproducible within 3%) detector of surface dose and exit dose as they exhibit a water-equivalent thickness that is independent of energy and angle of incidence. We believe they offer a unique opportunity in their application to *in vivo* surface dose measurement.

SU-FF-T-321

Micro-Computed Tomography: A Tool for the Determination of the Sensitive Volume of Cylindrical and Plane Parallel Ion Chambers

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Purpose: To use micro-computed tomography (micro-CT) as a tool for non-destructive imaging of air ionization chambers for independent sensitive volume determination and quality assurance of the chambers. **Methods and Materials:** A GE Locus Micro-CT imaging system was used to acquire high-resolution images of several common small-volume chambers (Exradin T11 plane-parallel chamber and Exradin A1SL cylindrical chamber). Initial scans were taken of these chambers with a 4cm field of view, 80kVp energy, 450μA tube current, 399 views, and 400ms exposure time per view. Images were reconstructed with 89μm pixel size. GE MicroView visualization software was used to determine the chambers´ air volumes for comparison with the manufacturer´s specifications. The ability of micro-CT to differentiate materials and the effect of high density materials on image quality was assessed. In addition, four Exradin A1SL cylindrical chambers were imaged with an increased number of views (720) and acquisition angles (360°) and reconstructed with 20μm pixel size. Air volumes from all of the chambers were compared to the chamber relative ionization signals generated in a 10x10cm^2 reference field from a Varian 2100C/D linac. **Results:** The air cavity volumes derived from the micro-CT images agreed with nominal volumes given by the manufacturers within 5% for both the cylindrical and plane parallel chambers. The relative response of the cylindrical chambers agreed with the relative volumes (semi-automatic method) within 2%. The presence of the connecting cables or pins within the chambers did not affect the ability to accurately visualize the sensitive air volumes. **Conclusions:** Micro-CT is a promising tool for the measurement of ion chamber air volume and potentially for determining calibration factors for use in dosimetry. These high resolution images could also prove useful as input to Monte Carlo simulations and the calculation of ion chamber response factors from first principles.

SU-FF-T-322

Miniature TLDs for Use in Beta Dosimetry

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Purpose: To demonstrate the production and utility of new miniature thermoluminescent dosimeters (TLDs) for use in electron fields such as those generated by $^{90}Sr/^{90}Y$ intravascular brachytherapy (IVBT) sources **Method and Materials:** Square lithium fluoride Harshaw TLD rods were cut into 1x1x0.5mm^3 "half-microcubes" for measurements of dose near a Novoste Beta-Cath $^{90}Sr/^{90}Y$ IVBT source pellet. Calibration exposures were performed with a Tracerlab RA-1 $^{90}Sr/^{90}Y$ ophthalmic applicator directly traceable to the NIST absorbed dose to water standard. All beta exposures were made in liquid water since it is the reference medium of interest. TLDs were read 24 hours post-exposure using a Harshaw 3500 planchet reader. TLD mass was tracked throughout the investigation, and individual TLD response characterization factors were determined from ^{60}Co exposures before and after each $^{90}Sr/^{90}Y$ exposure. **Results:** Radial depth dose measurement (and consequently radial dose function) results show slightly decreased volume averaging effects and increased precision of half-microcubes compared to standard 1x1x1mm^3 microcubes. Half-microcube measurements also correspond within uncertainty estimates to radiochromic film data and to data published by Soares et al (Med Phys, 25(3), 1998), which is the current NIST standard for IVBT beta sources. Monte Carlo statistical modeling with the MCNP5 transport code served to corroborate the measured radial dose function. **Conclusion:** Particularly for investigation of beta emitting sources, decreasing the volume over which TLDs average dose provides slightly increased precision in the measurement of relative dose rate at the 2mm reference depth. Precision changes from 12.2% for microcubes to less than 11% for half-microcubes at the 95% confidence interval. Both sets of measurements also avoid the experimental uncertainty inherent in most current published work by eliminating the conversion to water from data taken in water-mimicking media. TLDs were used to take advantage of their relatively well-known response to changes in energy, dose, and dose rate.

SU-FF-T-323

MLC IMRT Vs. Solid Compensators Based IMRT – Comparison of Various Clinical Cases

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Purpose: To compare multileaf collimator (MLC) intensity modulated radiation therapy (IMRT) with solid compensator based IMRT in order to demonstrate the feasibility and accuracy of solid compensator based IMRT. **Method and Materials:** Using the CMS radiotherapy planning system a sequence of two separate IMRT plans were prepared using superposition algorithm. First plan in each sequence delivered IMRT by means of the MLC, whereas the second one delivered IMRT by means of solid compensator. Quality Assurance (QA) IMRT was performed on a 2100CD Varian linear accelerator for both plans. For the QA measurements we utilized a 120-leaf Millennium MLC with 0.5 cm resolution and brass compensators (milled by DECIMAL INC.). Cases for different sites, e.g. head and neck, chest, abdomen, pelvis were investigated using 6 or 16 MV photons. Number of delivered monitor units, intensity map shapes and the dose distributions for GTV, CTV and OAR were compared for both plans. **Results:** Preliminary results indicate that solid compensator plans use significantly less monitor units and deliver smaller dose to the OAR as compared to the MLC plans. Moreover, solid compensators offer generally better resolution of intensity maps than MLC. Finally, in the process of segmentation, MLC IMRT changes DVH. In contrast, solid compensators by avoiding segmentation process of intensity maps, leave DVH unchanged between original, optimized plan and deliverable plan. **Conclusion:** The presented comparison demonstrates that solid compensator based IMRT is feasible. In addition, solid compensator based IMRT can provide clinical advantage over MLC IMRT for some treatments.

SU-FF-T-324

Modifications of Megavoltage Photon Beams for Gold Nanoparticle-Aided Radiation Therapy (GNRT): A Monte Carlo Study

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Purpose: To produce megavoltage photon beams capable of achieving clinically significant (> 10%) macroscopic tumor dose enhancement during *gold nanoparticle-aided radiation therapy (GNRT)*. **Method and Materials:** *GNRT* is an emerging treatment modality currently under development, based on the following observations: a) high tumor specificity of gold nanoparticles due to passive extravasation; b) significant tumor dose enhancement during x-ray irradiation as a result of increased photoelectric absorption due to high atomic number (Z) of gold. A previous Monte Carlo study found that no meaningful tumor dose enhancement would occur during *GNRT* with typical megavoltage photon beams, even after the removal of the flattening filter from linear accelerators. Therefore, the current Monte Carlo study investigated a number of ways to further increase the amount of low energy photons in the beam and consequently to achieve clinically significant tumor dose enhancement with photon beams in megavoltage range. Specifically, the macroscopic tumor dose enhancement under the identical geometry was calculated using the BEAMnrc/DOSXYZnrc code as the following conditions changed: the energy of electron pencil beam incident on the target, the target thickness, and the target material. **Results:** The current results showed that the macroscopic dose enhancement up to 40 and 18% across the tumor volume could be achievable with unflattened 2 and 4 MV photon beams, respectively, at a reasonable gold concentration of 3% within the tumor, after the proposed changes in target thickness and material. These beams were found capable of producing clinically acceptable treatment plans for *GNRT*, in spite of their softer photon energy spectra and larger buildup doses, compared to conventional megavoltage beams at the same nominal photon energies. **Conclusion:** Clinically significant tumor dose enhancement could be achievable during GNRT with megavoltage photon beams, provided that the proposed modifications to linear accelerators are made.

SU-FF-T-325

Modifying the BEAMnrc Phase-Space to Match Monte Carlo and Measured Dose Distributions

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Purpose: To present a method for improving agreement between clinically measured and Monte Carlo (MC) calculated dose distributions (profiles and PDDs) in water for the full range of field sizes. **Method and Materials:** Linac beam characteristics are modeled using BEAMnrc code that produces particle phase space above the secondary collimators as a new "source" in MC calculations. We assume that the photon energy spectra, represented in the phase space as achieved by the BEAMnrc model and electron beam characteristics, are reasonably accurate. The 3D dose distributions generated from MC and measured data are then used to modify the weights of each particle in the phase-space. The weight modification occurs through a few (typically 3) iterations and new weights are proportional to the ratio of the measures to MC calculated dose at a point where primary photon crosses the dose matrix plane. One-dimensional (assuming radial symmetry), 2D and 3D correction techniques were investigated. De-noising of the modified phase space has also been performed to reduce the "latent" dose uncertainty. **Results:** The method has been applied to our 6 MV and 18 MV beam models and allowed to reduce MC/measured beam profile differences from ~3% to less than 1% for 6 MV beam, and from ~5% to ~1% for 18 MV in the central region of the beam. It also reduced the difference between measured and calculated dose from over 15% to less than 3% in the penumbra of the diagonal profile of the 40 x 40 cm^2 field. **Conclusion:** The developed technique provides a relatively simple alternative to a very time-consuming process of fine-tuning BEAMnrc parameters. Initial BEAM model has to be "reasonably accurate" (producing results within ~5% agreement to measured data) prior to correction. 2D correction technique showed optimal performance providing required dose agreement and performing fasted than 3D correction.

SU-FF-T-326

Monte Carlo Based Simulation and Analysis of SRS X-Ray 6 MV Beam Tenth-Value-Layer Data for Common Shielding Materials

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Treatment room shielding design depends on barrier attenuation data. It is common practice to use tenth-value-layers (TVLs) or related quantities measured for a given beam quality and shielding material. This

investigation has applied Monte Carlo simulation to accurately determine the first, second and third TVLs for the three most common building materials: ordinary concrete, lead, and steel (iron). The radiation beam is 6 MV x-rays coming from a robotically mounted stereotactic radiosurgery (SRS) accelerator which has a maximum field diameter of 6 cm at 80 cm from the target. The first three TVLs are presented for a range of field sizes up to the broad beam equivalent of a 40 cm by 40 cm field at 1 m. The x-ray spectrum used to perform these simulations was generated for the CyberKnife™ accelerator with the BEAMnrc Monte Carlo code. This spectrum was used as input to the MCNP5 Monte Carlo code, to predicted tissue-maximum-ratio (TMR) values for a 6 cm diameter field (at 80 cm from the target) and benchmarked against measured TMR data. The MCNP5 code was used to simulate all barrier transmission factors, keeping the standard error of each data point below 1% of the mean. The results show that SRS TVLs change rapidly with the diameter of the radiation field incident on the barrier (with a slower rate of increase above about 15 cm diameter). Also analyzed were the characteristics of TVLs (specifically, the ordering TVL_1, TVL_2, and TVL_3) as a function of field diameter at the barrier for all materials, with special attention given to the TVL properties in iron. The TVL results compare very well with previously measured concrete TVLs for the SRS machine and, also, with published broad-beam 6 MV TVL data for all three barrier materials.

SU-FF-T-327

Monte Carlo Dose Calculations in Homogeneous and Heterogeneous Media: A Comparison Between the PMCEPT Code and the MCNP5, EGS4, DPM Codes and Measurements

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The Monte Carlo method for high-energy photon and charged particle transport is the most accurate means for predicting dose distributions in radiation treatment of patients. Owing to rapid development of computer hardware and network technologies the use of this method is not restricted only to big research centers any more. A new parallel Monte Carlo electron and photon transport (PMCEPT) code [Kum and Lee, J. Kor. Phys. Soc. **47** (2005) 716] for calculating electron and photon beam doses has been developed based on a three dimensional geometry defined by computerized tomography (CT) images and implemented on the Beowulf PC cluster. The PMCEPT code was validated on the homogeneous and multi-layered targets for megavoltage electron beams by comparing with the results of experiments and calculations from conventional Monte Carlo codes of the MCNP5, EGS4, and DPM. The computing time of the PMCEPT code was approximately twenty times faster than that of MCNP5 on the IBM ThinkPad X40 (laptop) with 1.2-GHz CPU and 512-MB ram memory operated by RedHat Linux 9. The PMCEPT results in general agreed well with others in homogeneous and heterogeneous media within a maximum of 2--3 % error. At the conference, we will show various benchmark results for the PMCEPT. This work was supported, in part, by the SRC/ERC program of MOST/KOSEF (grant number: R11-1999-054).

SU-FF-T-328

Monte Carlo Dosimetric Evaluation of Patient Intra-Fraction Motion

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Purpose: to include the patient intra-fraction motion into a Monte Carlo-based treatment planning system. **Materials and Methods:** the PENELOPE Monte Carlo code was used along with a mathematical phantom consisting of a target shape (water) that surrounds a critical structure (bone). Both structures are embedded in a cylindrical water phantom. Two types of motion were modeled: shifting and deformation both periodic in time. It is assumed that deformation does not alter the density of the structure and that no movement occurs during the tracking of a single particle history. A PENELOPE subroutine was designed that performs the simulation in the following way: at the beginning of a history a configuration of patient geometry is sampled from a probability distribution with equi-probable bins. Each bin describes a particular state during the evolution of the geometric configuration. Once the configuration is selected, a history is started and followed under the geometry selected until it is terminated; the process is repeated for another geometry configuration. The simulations were carried out using a point source emitting a published Varian 15MeV x-ray spectrum at an SSD of 100cm, and for probability distributions with 5, 10 and 20 bins, with amplitude of movement or deformation in the order of 1cm. At the end of the simulation, the calculated dose arrays for each configuration are mapped onto a static reference configuration for display. **Results:** when a comparison is made at selected points between the simulation for the reference configuration and the composite simulation, discrepancies on the order of 2% to 10% are found, with the larger differences seen at the edges of both the target and the critical structure. **Conclusions:** the work here presented represents a first step towards fully modeling the movement of organs during the treatment planning process. Experimental verification of the results is underway.

SU-FF-T-329

Monte Carlo Dosimetric Study of the Flexisource Ir-192 HDR Source

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Purpose: Brachytherapy with high dose rate (HDR) sources of ^{192}Ir is a usual practice in clinical brachytherapy today. The TG43 U1 update report recommends that accurate dose distribution data of the brachytherapy source in use should be obtained experimentally or by Monte Carlo (MC), to be used as input in the HDR Treatment Planning System (TPS). The purpose of this study is to obtain the dose rate distribution in liquid water media for the Flexisource HDR ^{192}Ir source (Isodose Control GmbH, Germany) using the Monte Carlo method to obtain the TG43 U1 parameters and the 2-D rectangular dose rate table. **Material and methods:** The MC code GEANT4 (7.1 version) was used to estimate dose rate in water and air-kerma strength around the Flexisource Ir-192 source following the TG43 U1 recommendations. All the details about the design an material of the Flexisource have been included in the simulation. **Results:** A complete dosimetric dataset for the Flexisource is presented. TG43 dosimetric functions and parameters have been obtained as well as a 2-D rectangular dose rate table, consistent with the TG43 dose calculation formalism. **Conclusions:** The dosimetric parameters and functions obtained for the Flexisource have been compared with that obtained in the literature for others HDR sources, showing that the use of specific datasets for this new source is justified. This dataset can be used as input in the TPS and to validate its calculations. As policy of BRAPHYQS-ESTRO task group, this dataset will be incorporated to the website: http://www.uv.es/braphyqs available to users in excel format.

SU-FF-T-330

Monte Carlo Investigation of Dose Perturbation by Hip Replacements in Intensity Modulated Radiotherapy of Prostate Cancer

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Purpose: To quantify the effects of hip replacements (prostheses) on IMRT dose distributions for prostate cancer and to determine their dose perturbations in IMRT treatment caused by the daily setup uncertainty and the inter-fractional motion of prostate. **Method and Materials:** Different IMRT plans were generated with different beam arrangements for each selected prostate cancer patient with a hip prosthesis, and both uniform geometry and a bulk-density assignment to the prosthesis were used in the planning dose calculation. Those plans were then recomputed on the EGS4 based Monte Carlo planning system with the shifts of the position of the prostates and isocenter, which were used to simulate the uncertainties in the daily routine treatment. Results were compared with and without the shifts for the same plans or between plans with uniform geometry and bulk-density assignment to the prosthesis. Isodose distributions and DVHs were used to quantify the perturbations of dose caused by the hip replacements. **Results:** For the IMRT plans with one lateral beam passing through or close by the prosthesis, our results showed that the dose perturbations caused by the internal movement of the prostate and the uncertainty in patient positioning could be clinically significant. Since the intensity for the beam passing through the prosthesis is highly modulated in the optimization due to the high density of the prosthesis, the changes on the uniformity of the dose to the target and the effects to the critical structures were more significant compared with the plan without the presence of a hip prosthesis. **Conclusions:** This work indicates that the potential significant

dose perturbations could happen due to setup uncertainties and inter-fractional motion of the prostate in the presence of a hip prosthesis for the treatment of prostate cancer.

SU-FF-T-331

Monte Carlo Simulation of Backscatter in a Flattening Filter Free Clinac

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Purpose: Report the influence of backscatter to the chamber signal in a flattening filter free Varian 2100 Clinac. **Method and Materials:** Monte Carlo simulations of the chamber signal as a function of various field sizes in a flattening filter free treatment head were performed with MCNPX. Benchmarking simulations were carried out with a flattening filter in the beamline and compared with published results. **Results:** The measured and calculated backscatter contribution to the ionization chamber signal of a system with a flattening filter showed good agreement with published data. Simulations without the flattening filter showed no significant differences to the data with the flattening filter . **Conclusions:** Backscatter into the ionization chamber must be taken into account, when interpreting dose to a patient, because the monitor chamber signal will change as a function of field size. In the case of a flattening filter free beamline, the differences to a standard beamline are smaller than the statistical uncertainties of both measurements and simulations, and it can be treated as a conventional setup with a flattening filter. Experiments and simulations did not show evidence of any additional effects on backscatter, when the flattening filter is removed from the system. **Conflict of Interest:** Research is sponsored by Varian Medical Systems

SU-FF-T-332

Monte Carlo Simulation of Tomotherapy: Derivation of a Dual Source Model for Treatment Planning

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Purpose: To simulate a commercial Tomotherapy unit using Monte Carlo methods and to derive a dual-sources model for the treatment planning. **Method and Materials:** The EGSnrc/BEAMnrc codes were used to simulate the linac head geometry of a Tomotherapy unit (HiArt, Tomotherapy Inc.). Various component modules were used to consider the head design including the target, primary collimator and multi-leaf collimators (MLC). The percentage depth dose (PDD) and beam profile in a water phantom were generated using the phase-space data below MLC and then compared to measurements. Using tools from the BEAMnrc package, the phase-space data above MLC were used to extract a dual source model, consisting of a ring photon source located at the target and another ring source located at the primary collimator. The source model was verified in the following steps: (1) the source model was used to reconstruct the phase-space data below MLC, which, in turn, was used to calculate PDD and beam profiles, (2) the PDD and beam profiles generated by (1) were compared to those generated by the original phase-space data. **Results:** It was found that the PDD and beam profiles using Monte Carlo methods (the phase-space data) agreed well (within 2%) with the measurements. The dose distributions using the source model were found to agree with (within 2%) the Monte Carlo and measurement data, indicating the source model is suitable to replace the Monte Carlo simulation for dose calculations in routine treatment planning. **Conclusion:** Monte Carlo simulation of a Tomotherapy unit has been carried out and a source model suitable for dose calculations in treatment planning has been derived. This model is useful for better understanding linac head design and for improving the accuracy and efficiency in dose calculations for Tomotherapy. **Conflict of Interest:** Research sponsored in part by TomoTherapy Inc.

SU-FF-T-333

Monte Carlo Simulations Using Whole-Body Pediatric and Adult Phantoms as Virtual Patients to Assess Secondary Organ Doses in Proton Radiation Therapy

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Introduction: Early cancer detection combined with new treatment technologies has resulted in higher numbers of long-term cancer survivors. The risk of radiation-induced secondary cancers to tissues away from the PTV is a growing concern in particular for pediatric patients. The focus of this project is to use whole-body pediatric phantoms in Monte Carlo dose calculations in order to determine the effective dose from secondary radiation in patients undergoing proton treatment. **Methods:** Age and gender specific pediatric phantoms have been implemented into the Geant4 Monte Carlo package for organ dose calculations. A proton therapy treatment plan for a pediatric head and neck tumor case was chosen to address the significance of age dependent phantoms for radiation protection calculations. To mimic radiation therapy treatment, the setup of the phantom position was based on field parameters (based on a full treatment head model), including gantry angle, couch angle, and iso-center position. We distinguish between secondary radiation from the treatment head and secondary radiation generated within the patient. **Results:** Results using an adult phantom as well as phantoms of a 4-year old female and an 11-year old male were analyzed. Organ doses and radiation and tissue weighting factors were used to calculate the effective dose. For proton treatments with double-scattering system, range modulator and aperture, a significant number of secondary neutrons are generated in the treatment head. More important, differences between phantoms (age dependent) were found with respect to dose to specific organs and relative importance of neutrons generated in the patient versus neutrons from the treatment head. **Conclusion:** We present results of doses to various anatomic sites in the human body for whole-body phantoms. The magnitude of secondary dose in organs/tissues depends on the distance from the PTV. For the first time, the significance of age-dependent phantoms for secondary dose calculations was studied.

SU-FF-T-334

Moving From Measurements Toward Independent Computer Calculations for Patient-Specific IMRT QA

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Purpose: A medical physicist's time and resources are always balanced between many clinical obligations. It would be advantageous for physicists to forgo measurements of IMRT plans in lieu of independent computer calculations. In this work, we investigate the appropriateness of independent computer calculation monitor unit checks of IMRT treatment plans in place of physical measurements before treatment delivery. **Method and Materials:** This study consists of one academic and one community institution with active IMRT programs. Each institution followed their in-house IMRT procedures for treatment planning and quality assurance. The independent computer calculation software was common between the institutions (IMSure QA program; Standard Imaging, Middleton, WI). The treatment sites considered were prostate and head and neck. Process behavior charts were used as the quality assurance tool for investigation. A correspondence between the measurements and IMSure calculations was established by using time-ordered data to demonstrate that IMRT measurements and IMSure calculations were predictable and independently stable processes. Quantitative justification for discontinuing measurements in place of computer calculations was achieved once process stability was established. **Results:** Natural process limits were determined to be ±1.8% for prostate case measurements and ±1.5% for the corresponding IMSure calculations. Limits for the head and neck cases were larger at ±7.1% for measurements and ±12.1% for the corresponding IMSure calculations. We found that that stable process behavior limits could be calculated in as few as 15 cases for prostate but head and neck cases required at least 25 data points before the two processes showed concomitant stability. **Conclusion:** Process behavior charts as a part of an IMRT quality assurance program can provide a quantitative justification for

when it is appropriate to discontinue measurements in lieu of independent computer calculations. The number of cases that need to be measured depends on treatment site and the individual quality assurance program.

SU-FF-T-335

MU Variation for Total Body Irradiation (TBI)

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Purpose: To determine a simplified formula to calculate monitor unit (MU) for total body irradiation (TBI) for 6 MV photon beams. **Method and Materials:** Patient data were accumulated for TBI with 6 MV photon beams between January 2002 and February 2006. The dependence of MU on SAD, patient thickness, and field sizes were examined for four different linear accelerator types. **Results:** MU depends strongly on SAD but is almost independent of the linear accelerator types. Among the 47 patients examined, the depth varied between 6.5 and 21.5 cm (mean and s.d.11.5 ± 3.6 cm), the field sizes varied between 20 and 50 cm (mean and s.d.35 ± 8 cm) and SAD varied between 492 and 591 cm. MU is linearly proportional to the thickness of patient separation and, to a lesser extent, linearly dependent on the equivalent patient field size. To deliver 200 cGy, the mean and standard deviation of $MU*(100/SAD)^2$ is 113 ± 11 for all patients examined. **Conclusion:** To deliver 200 cGy with 6 MV photon beams, MU can be determined using a formula $MU*(100/SAD)^2 = 2.63\ d + 82.6$ to within an accuracy of 5.7% for most of patients examined. To increase the accuracy further, requires taking into account the field size dependence.

SU-FF-T-336

Multi-Slice Tomotherapy Delivery Methods Using a Novel Multileaf Collimator

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Purpose: In this study, we present an initial dosimetric investigation of multi-slice tomotherapy delivery methods using a novel multileaf collimator design. **Method and Materials:** A compact multileaf collimator design for multi-slice tomotherapy is under investigation. Intensity modulation is achieved through binary actuation of adjacent pivoting leaves with multiple leaf banks employed to deliver multi-slice tomotherapy. Pitch may be determined by the ratio of the couch travel distance for a complete gantry rotation divided by the slice width at the axis of rotation. For multi-slice tomotherapy the concept of pitch is complicated by the use of multiple collimated slices and differing fan beam divergences. We have studied the dosimetric effect of: (a) using regular pitch, where a given collimated slice does not irradiate beyond the adjacent slice and (b) using multi-slice pitch, where different collimated slices irradiate the same region in the patient. Other novel aspects of tomotherapy delivery with the multi-slice collimator are presented. **Results:** The multi-slice pitch delivery method allows for treatment of extended volumes greater than the spacing between slices, without the junctioning effect of the regular pitch method. A pitch less than 1 may be achieved when considering irradiation from different collimated slices and is a determined by the slice spacing, slice width and couch travel. The difference in fan beam divergence in the axial direction may be clinically advantageous. Single-slice techniques may also benefit from non-coplanar delivery. **Conclusions:** A method for multi-slice tomotherapy delivery is investigated. Dosimetric results are presented for various methods of dose delivery including a multi-slice pitch method for extended treatment lengths. Multi-slice delivery will result in shorter treatment times for both linac and cobalt-based tomotherapy systems and development of novel radiation therapy techniques. **Conflict of Interest:** Research was supported in part through a licensing agreement with TomoTherapy Inc.

SU-FF-T-337

Multiobjective Inverse Planning Optimization: Adjustment of Dose Homogeneity and Urethra Protection in HDR-Brachytherapy of the Prostate

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Purpose: Multiobjective optimizations are performed to evaluate the inverse planning (IP) ability to adjust the dose homogeneity and the urethra protection in HDR brachytherapy of the prostate. **Materials and Methods:** An IP is an anatomy-based optimization guided by dose objectives specified for each organ extracted from medical imaging. It selects automatically the active dwell positions and optimizes the dwell times to fulfill the dose objectives. It is setup to maximize the prostate dose coverage while taking into account other clinical objectives like the dose homogeneity and the organs at risk protection. Multiobjective optimizations are performed using the IP for one small (23cc), one intermediate (35cc) and one large (80cc) prostate. 10 inverse plans were generated with different compromises between dose coverage and dose homogeneity. This was performed first with the prostate alone and then with all the organs at risk. In addition, 10 inverse plans were generated with different compromises between dose coverage and urethra protection. 90 DVH were generated and analyzed. **Results:** When only the prostate is included, the prostate V100 varies from 100% to 97% and the homogeneity index (HI) from 0.06 to 0.68. When all the organs at risk are included, the prostate V100 varies from 97% to 91% and the HI from 0.52 to 0.72. When the urethra protection is increased, the prostate V100 varies from 100% to 89%, the urethra V100 from 100% to 89%, the urethra V120 from 87% to 0% and the urethra V150 from 3% to 0%. **Conclusion:** For simple cases where only a target is defined, the dose homogeneity is adjustable with the IP. For complex cases where organs at risk are added, this anatomy-based optimization automatically adjusts the dose homogeneity to protect the urethra. Additional organ protection can be achieved with specific penalty. This research was supported by Nucletron Corporation.

SU-FF-T-338

MVCT Superiority Over KVCT in Assessment of Electron Density for Treatment Planning

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Purpose: Accurate assessment of electron density (ρ_{e-}[electrons/cm^3]) is essential for radiotherapy treatment planning, especially for protons. Measurements of ρ_{e-} are typically performed with kilovoltage CT (kVCT) and its calibration assumes that object is tissue equivalent. In this work, we demonstrate that kVCT presents confusing information when objects have varying atomic number (Z). At the same time, we demonstrate that megavoltage CT (MVCT) may be preferred over kVCT in treatment planning since its calibrated pixel value, or CT number, is proportional to ρ_{e-}, independent of atomic number(ignoring pair production), and is suitable for non-tissue equivalent materials(e.g. hip prostheses). **Method and Materials:** A dual-energy kV & MVCT benchtop is used to image a tissue-equivalent phantom as well as samples with various combinations of ρ_{e-} and Z. **Results:** The plot of CT number to ρ_{e-} for the tissue equivalent phantom is non-linear for the kVCT, but linear for the MVCT. For the non-tissue equivalent samples, the MVCT number increases linearly with ρ_{e-} for all the samples, however the kV CT number to electron density is complicated by the two material components of the kV attenuation: atomic number and electron density **Conclusion:** For all the samples presented the MVCT number increases with the electron density of the sample. The kVCT number assessment of electron density is only reliable for low atomic number materials. Beam hardening affects the kVCT number even for relatively small samples. Beam hardening effects for MVCT is slight and only apparent in large patients. Ignoring image-quality to dose considerations, MVCT should be preferred for electron density assessment. **Conflict of Interest:** This work was partially supported by grant from the NIH (PO1 CA088960) and a contract from TomoTherapy Inc.

SU-FF-T-339

Neutron Fluence Measurements Around the Siemens Oncor Medical Linear Accelerator Utilizing Gold Foil Activation

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Introduction: Neutron production in photon beams from high energy Linacs is a concern in radiation therapy centers. Neutrons are produced in the accelerator's head when high energy photons strike high Z materials of the target. Through a (γ, n) reaction, energy from the photon gets transferred to the atomic nucleus which then decays via the ejection of a neutron. In this paper, we measured the neutron fluence produced from the new Siemens Oncor using the Moderated Gold Foil Activation Method. In the process, neutron head leakage, in-beam neutron contamination, the Q factor used for shielding purposes, and an estimate of the dose a patient may receive from a typical course of treatment were also measured and will

be reported. **Methods:** Two gold foils were calibrated to provide a fluence per activity per gram conversion factor. The gold foils were then placed between two 3"x6" polyethylene cylinders which were covered in 0.025" cadmium metal. The gold foils were placed at distances of 112cm and 140cm from the target in the patient plane and exposed to doses that ranged from 5-10 photon Gy. After a 24 hour wait period, the activated gold foils (Au-198) were read on a Capintec 3000 MCA with a ROI set at a value of 400 to 424 KeV with the center at 412 KeV. The calculated activity at the time of irradiation was used to determine the fast neutron fluence. **Results:** The average neutron fluence measured from a 20cm x 20cm field was 1.6 $x10^{6}$ +/- 7.7 $x10^{4}$ $n/cm^2/Gy$. The Q value was calculated to be 0.27 $x10^{12}$ +/- 0.3 $x10^{11}$ n/Gy. **Conclusion:** The measured neutron fluence and calculated Q value from the Siemens Oncor is slightly higher than the published values for other Siemens accelerators, but is within the range for other accelerators.

SU-FF-T-340

Neutron Spectra Measurements For Fast Neuron Brachytherapy Effective Dose Evaluation

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Purpose: We are developing a miniature neutron generator capable of brachytherapy, contact therapy and perioperative therapy applications. The neutrons are produced at 14MeV in a thermonuclear reactant target located at the end of a needle. The fast neutron effective dose depends on the lineal spectrum of charged particles produced by neutron interactions in tissue. Neutron interaction probabilities, cross sections, vary with neutron energy and the neutron spectra change with transmission through tissue. The change in spectra of initially 14MeV neutrons with tissue depth in brachytherapy is in itself not dramatic because the neutron mean free path is 10cm. But more seriously, the LET of neutron scattered protons increases with the inverse of proton energy and higher LET protons (bellow 120keV/micron) have increased relative biological effectiveness. The measurement of neutron spectra below 2 MeV is therefore important for understanding the mechanism of effective dose. In this paper, we will describe our development of a double scatter neutron spectrometer (DSNS) that has proven effective in low energy neutron spectral measurements. **Method and Materials:** The DSNS consists of detector planes of two liquid organic scintillators separated by 18cm. A neutron that scatters in the first plane starts a timer which is stopped by a coincident neutron detection signal for the same neutron in the second detector plane. Energy of the scattered neutron is determined by time-of-flight over the distance between detectors, which is the incident energy when the source is aligned with the detector axis. **Results:** The useful energy range of the DSNS is 0.3MeV to 5MeV and is dependent on the separation distance of the detector planes.**Conclusion:** The DSNS should be useful for measuring the low energy neutron component of our brachytherapy accelerator based source.

SU-FF-T-341

New BEAMnrc Tools for Photon and Electron Beam Model Analysis

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Purpose: Accurate radiotherapy planning requires precise and adaptable beam models. A beam model must be able to reproduce the full range of output on a clinical accelerator if a 2%/2mm or better accuracy goal is to be met. Most beam models have not been able to consistently meet this goal. While beam models can be based largely on measurements, Monte Carlo calculations can also be useful for determining the needed parameters and the breadth of flexibility required. In particular, Monte Carlo calculations are critical for exploring the impact of asymmetries in the accelerator geometry. As part of an effort to develop flexible beam models meeting a 2%/2mm accuracy goal, we have developed new tools for use with BEAMnrc. **Method and Materials:** A version of beamnrc.mortran incorporating a lateral shift for each component module has been designed, allowing the impact of laterally offsetting electron beam and accelerator elements to be evaluated. The point source model has also been modified to permit a non-normal beam angle to allow a sensitivity analysis to include an angular distribution at the focal spot with a tilted beam. In addition, we have developed a new component module RECT which includes a simple rectilinear phantom as part of BEAMnrc, removing the necessity of using DOSXYZnrc for simple geometries. **Results:** By bypassing the need for a phase space file, RECT can facilitate high-statistic runs for large field configurations by eliminating restrictions on disk space. RECT can also take advantage of the homogeneity in a water phantom by allowing photon step sizes beyond individual voxel boundaries, speeding up the simulation. **Conclusion:** The inclusion of lateral offsets in Monte Carlo beam models has been demonstrated to reproduce asymmetries of several percent in large electron fields, and is being used to study the 1-2% asymmetries found in clinical photon fields.

SU-FF-T-343

Normalized Data for the Estimation of Fetal Radiation Dose From Radiotherapy of the Breast

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There can be several reasons why a pregnant patient may receive a radiological examination. It could have been a planned exposure or the exposure may have resulted from an emergency when a thorough evaluation of pregnancy was impractical. Sometimes the pregnancy was unsuspected at the time of the examination and with younger women being diagnosed with breast cancer, the likelihood of this will increase in the radiotherapy departments. Whatever the reason, when presented with a pregnant patient who has received a radiological examination involving ionizing radiation, the dose to the fetus should be assessed. However, a major source of uncertainty in the estimation of fetal absorbed dose is the influence of fetal size and position as these changes with gestational age. We have investigated doses to the fetus from radiation therapy of the breast of a pregnant patient using an anthropomorphic phantom. Data for estimating fetal dose that takes into account the size and depth within the maternal abdomen for different treatment techniques have been provided. The data indicate that fetal dose is dependent on both depth within the maternal abdomen and gestational age and hence these factors should always be considered when estimating dose. The data shows that fetal dose can be underestimated up to about 10% or overestimated up to about 30% if the dose to the uterus is assumed instead of the actual fetal dose. It can also be underestimated up to about 23% or overestimated up to about 12% if a mean depth of 9cm is assumed, instead of using the actual depth of the fetus within the maternal abdomen.

SU-FF-T-344

On the Equivalency of the Population and Individual TCP Models

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Purpose: To demonstrate that the functional form of the population tumor control probability (TCP) model is well approximated by the individual TCP model. **Method and Materials:** Due to inter-parameter relations, the parameters of the population based Poisson TCP model in the limit of large heterogeneity reduce to the geometric parameters D_{50} and γ_{50}:[1] $TCP_{pop}=0.5erfc[\pi^{0.5}\gamma_{50}(D_{50}/D - 1)]$. On the other hand the individual TCP model can also be written in the terms of the geometrical characteristics of the dose-response relationship - D_{50} and γ_{50}: $TCP_{ind}=0.5\exp[2\gamma_{50}/(\ln 2)(1-D/D_{50})] = \exp[-N_o \exp(-\alpha D)]$. For typical clinical values[2] of the parameters D_{50} and γ_{50}, we evaluate and compare the individual and population-based TCP models. **Results:** The two models are approximately equivalent for different values of D_{50} and γ_{50}. When plotted, the individual and population-based TCP models almost overlap over a wide range of doses for all D_{50} values and γ_{50} higher than 1. When γ_{50} is less than 1 both functions start to differ from one another. **Conclusion:** The equivalency between the individual and population TCP models is demonstrated. The individual TCP model has been observed to fit clinical datasets reasonably well, and this phenomenon may be attributed to the similarity of the models. When fitted to clinical data, the individual TCP model will produce parameter estimates completely emptied from their biological meaning and become purely phenomenological. 1. M. Carlone, B. Warkentin, P. Stavrev, and B. G. Fallone. "Fundamental form of the

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SU-FF-T-345

On the Suitability of Radiographic Film for Low Density Material Dosimetry and Photon Algorithm Verification

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Purpose: To assess potential errors in radiographic film dosimetry in low density materials and to compare film measurements to dose estimates of a commercial convolution/superposition photon (CSP) dose calculation algorithm. **Method and Materials:** A standard film phantom was modified by replacing water-equivalent slabs (30 HU) in its central portion with very low-density material (-960 HU) to produce a lung slab phantom. Experiments were performed irradiating this phantom with 6 and 18 MV photons and field sizes of 2x2, 5x5, and 10x10 cm with 13 films placed between slabs. With unprocessed film in place , the phantom was then imaged in a computed tomography scanner and Monte Carlo (MC) and CSP calculations were done for each field size and energy combination. The phantom was then rescanned without film and dose was recalculated using MC to estimate the effect of the film in the prior MC calculations. **Results:** Measurements and MC calculations demonstrated field size and energy-dependent dose perturbations at film planes in the low density material (up to 20% of maximum dose). In the phantom with film, central axis measurements and MC calculations matched within about 3%. The CSP algorithm was not perturbed by the film and overestimated dose in the low density region. Relying on film measurements alone would indicate a maximum overestimate of about 17% for 6 MV beams and 30% for 18 MV beams for the 2x2 cm fields. The filmless MC calculations show the true error to be about 6-9% higher. **Conclusion:** The error in CSP calculations will be underestimated if film is used as a dosimeter in very low-density materials. The use of somewhat denser lung-equivalent materials (*e.g.,* -700 HU) would likely result in reduced, but still significant, error estimates. Supported by NIH grant RO1 CA85181 and a grant from Sun Nuclear, Corp.

SU-FF-T-346

On Using Two Parallel Opposed Fields for Grid Therapy

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Purpose: To study the feasibility of creating well-aligned opposed grid fields and to show their dosimetric advantages for grid therapy. **Method and Materials:** A Varian MLC (multileaf collimator) is used to create two opposed grid fields. The key in getting the two opposed beams aligned collinearly is to restrict the grid size to the region near the beam axis. A larger grid can then be assembled from a series of smaller ones, each with its own isocenter. To give a more quantitative assessment as to what the maximum size of these grid subunits can be, we choose the criterion of no crossings between neighboring rays. The dosimetry was studied by sandwiching radiographic films between phantom blocks. **Results:** The mathematical analysis shows that the size of each of the subunit grids is governed by the series {1/3, 1/5, 1/7,…} of the SAD (source-axis distance), corresponding to the number of added columns; that is, two columns would reduce the "valid" grid coverage distance from the isocentric plane to 1/3 of the SAD, three columns to 1/5, and so forth. The percentage depth dose of a 1cm x 1cm opening along the beam axis is found to be 70% and 90% for the respective 6 and 18 MV photons traversing a water-equivalent material of 30 cm thick. **Conclusions:** Well-aligned opposed grid fields shaped by a MLC have been successfully demonstrated in this study. The method gives a much more dose uniformity in the areas of the grid openings as compared to a single grid field approach. This feature is important in treating a large size tumor, as such is the nature of grid application today.

SU-FF-T-347

Optimization of Dose Distribution for HDR Brachytherapy of the Prostate Using Attraction-Repulsion Model

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Purpose: To optimize dose distribution for high-dose-rate (HDR) brachytherapy for prostate cancer, we have developed a new algorithm named Attraction-Repulsion Model (ARM). In this study, we compared the ARM with geometric optimization (GO). **Method and Materials:** ARM was used to optimize the dose distribution by finding the best dwell time combination, and this model uses a feedback mechanism. ARM requires grids inside the clinical target volume (CTV) and critical organs. These grids generate attraction or repulsion based on specific dose constraints. After calculations were performed repeatedly until the attraction and repulsion forces reached equilibrium, the optimal dwell time distribution was established. We compared the ARM with GO for ten patients using dose volume histograms and some volume indices. **Results:** The CTV ranged from 23-48 cc and the CTV V150 ranged from 52-79 %, and 23-44 % for GO and ARM respectively. This indicates that the dose homogeneity indices as well as the conformal indices were higher for ARM than for GO. The urethra V150 was 0-99% and 0-1 % for GO and ARM respectively. **Conclusion:** ARM proved to be superior to GO in minimizing the dose to normal structures and improving dose homogeneity for the target while reducing the dose to normal tissues.

SU-FF-T-348

Optimize Spike Patterns For An Embedded Boost Technique For Gamma Knife Radiosurgery

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Purpose: With the Gamma Knife Automatic Positioning System, high dose spikes can be placed inside a target using 4-mm shots to boost the central target dose without affecting adjacent normal brain sparing. Potential applications of the technique include target boost when nearby critical structures such as optical structure limit the peripheral dose or increasing the dose to centrally hypoxic regions. This study investigates how the spatial distribution and height of the spikes can be optimized for this purpose. **Method and Materials:** A computer program was developed to optimize the pattern of spike boost placed over conventional Gamma Knife plans. The program first extracts the prescription isodose volume and then iteratively adjusts the positions and the heights of the spikes while accounting for the existing dose distribution. Different boost patterns were generated for both patient and phantom cases. The program calculated the stereotactic coordinates and weights of the spike shots, which were manually entered into the Leksell Gamma Plan for dose calculation and dose-volume evaluations of the modified treatment plans. **Results:** The total number of dose spikes and the maximum dose for the spike shots correlates with the target size ($R^2 > 0.9$). For the cases studied, an increase in average dose to the target of 15-28% was noted while the conformity index of target volume coverage remained unchanged. The dose to the adjacent normal brain (defined as the volume enclosed by half of the prescription isodose line excluding the target) remained unchanged to better than 2% of the maximum dose. Overall, spike patterns arranged along the radial direction consistently give a higher average dose to the target than for spikes arranged along the translational directions. **Conclusion:** Optimizing the shot weights and the spike patterns enhances dose to the target volume while maintaining normal brain sparing for Gamma Knife radiosurgery.

SU-FF-T-350

Optimizing the MLC Apertures for Conformal Radiotherapy with a Hybrid Algorithm

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Purpose: To develop a feasible technique to simultaneously optimize the shapes and weights of the MLC apertures for conformal radiotherapy planning. **Method and Materials:** The shapes of the MLC apertures are

optimized using the genetic algorithm (GA). There are several individuals in each generation of GA, and each individual includes a group of apertures, which number is equal to the number of pre-selected beams, i.e., each individual is a trial conformal plan. The initial aperture shapes are obtained by adding different margins to the target on Beam's-eye-view (BEV). The margins range from -1.0 cm (i.e., shrink) to 1.0 cm (i.e., expand), with a step of 0.2 cm. The apertures of all beams with 1.0 cm margin constitute the first individual, and the apertures with 0.8 cm margin constitute the second, etc. For the selected two individuals (parents), the crossover and mutation operation are applied to the corresponding two apertures of the two parents. After the loop of shape optimization with GA, the aperture weights are optimized with a conjugate gradient (CG) method. The shapes and weights are iteratively optimized. **Results:** A five-beam conformal plan is used for a head-and-neck tumor case. In the manual plan the weights of all apertures are set to unit, and the shapes are obtained by adding a 0.5 cm margin to the target on the BEV of each beam. About 2 minutes are taken to find the optimized plan. Both the dose distributions on CT slices and the DVH curves demonstrate the improvement of the optimized plan. **Conclusion:** This work indicates that the proposed GA and CG-based algorithm is feasible and efficient for the optimization of the shapes and weight of MLC apertures for conformal radiotherapy planning, and a better dose distribution could be achieved within clinically acceptable computation time.

SU-FF-T-351

Optimum Parameters An a Model for Tumor Control Probability Including Interpatient Heterogeneity: Evaluation of the Log-Normal Distribution

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Purpose: The heterogeneity of human tumor radiation response to is well known. Researchers have used the normal distribution to describe interpatient tumor radiosensitivity. However, many natural phenomena show a lognormal distribution. Lognormal distributions are common when mean values are low, variances are large and values cannot be negative. These conditions apply to radiosensitivity. The aim of this work was to evaluate the lognormal distribution to predict clinical TCP data and compare the results with the homogeneous (single α value) and normal distributions. **Method and Materials:** The clinically-derived TCP data for four tumor types: melanoma, breast, squamous cell carcinoma and nodes were used as the benchmark to fit the TCP models. Three forms of interpatient tumor radiosensitivity were considered: the lognormal, normal and δ-function (homogeneous). The free parameters in the models were the radiosensitivity mean, standard deviation and clonogenic cell density. The evaluation metric was the minimum square difference between the predicted and clinical data. **Results:** The normal and lognormal distributions match the clinical data significantly better than the δ-function distribution. The means and standard deviations of the normal and lognormal distributions are similar. Though the clinical data match was slightly better for the lognormal data, the difference was not statistically significant (p=0.13). The clonogenic cell density value yielding the best clinical data match (10^1-10^5) is much less than the expected tumor cell density (10^7-10^9). Three explanations are intratumor radiosensitivity heterogeneity, tumor 'stem' cells and multiple cells required for tumor growth. **Conclusion:** The lognormal and normal distribution of interpatient tumor radiosensitivity heterogeneity more closely describe clinical TCP data than a single radiosensitivity value. The lognormal distribution trends towards significance in its ability to match clinical TCP data compared to the normal distribution. The lognormal also has some theoretical and practical advantages over the normal distribution.

SU-FF-T-352

Output Verification and Clinical Implementation of Leipzig Applicators for Treating Small Skin Lesions by HDR-Brachytherapy Using Multiple Dosimetry Systems

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Purpose: The purpose of this paper is to provide a guide to commissioning the Nucletron Lepzig Applicators in a clinical setup for treating small surface lesions using HDR brachytherapy. **Method and Materials:** Recently we have acquired a set of six Leipzig Applicators (3 Horizontal applicators with inner diameters 1 cm, 2 cm and 3 cm and 3 Vertical with same diameter sizes) for our microselectron-HDR V2 afterloader. Initially we have measured dose rates for 3 Horizontal applicators using Standard Imaging Exradin A10 parallel plate ion chamber and films (gafchromic and EDR2). Since the sensitive area of this ion chamber is comparable to the effective field area for the smaller 1 cm diameter applicators we felt the necessity to verify the dose rates using gafchromic films as well as EDR2 film. We have also used MOSFET and a micro parallel plate chamber (Exradin A14P, provided by Standard Imaging) and small cylindrical chambers (Exradin A1SL,and A14SL) for independent verification of our measurements. **Results:** To implement these applicators for clinical use we measured surface dose rates and depth dose rates for each applicators using variety of dosimetry. We subsequently developed an Excel Spreadsheet program to compute dwell time for a given prescription and to print a plan report documentation for the treatment. **Conclusion:** In this presentation we compare our data with published data and describe the details of clinical implementation of these applicators.

SU-FF-T-353

Parameters Study for the Severity Acute Radiation Induced Skin Reaction for the Breast Cancer Patients

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Purpose: Radiation induced skin reaction is a common side effect for the breast cancer patient undergoing radiotherapy (RT). Severe acute radiation skin reaction (ARSR) not only brings distress to the patient, it may also cause an unexpected treatment delay and consequently reduce the treatment efficacy. It is important to understand the factors that cause ARSR and eventually to prevent or minimize it. **Method and Materials:** A retrospective study was conducted to 154 breast cancer patients who received a whole breast external photon beam treatment at source-to-axis distance (SAD) setup with 6MV or 6MV combined with 18MV photon energy at our hospital between 2003 and 2005. The relation between ARSR, the source-to-surface distance (SSD) and treatment technique was evaluated in this study. The treatment techniques included conformal three-dimensional (3D) treatment and intensity-modulated radiation therapy (IMRT). These techniques were further classified into: (1) 3D open field, (2) 3D with cerrobend block, (3) 3D with MLC, (4) IMRT sliding window, and (5) IMRT step-and-shoot. Receiver operating characteristic (ROC) curve and p-value were applied for the statistic analysis. **Results:** Out of total 154 patients, 21 (13.6 %) patients developed ARSR. The results showed that ARSR was sensitive to SSD variation when the patient was treated with 3D MLC and IMRT sliding window treatment techniques (Az=0.9±0.12 with p-value=0.014, and Az=0.8±0.08 with p-value=0.017, respectively). And ARSR was non-sensitive to the SSD variation when patient treated 3D open field and 3D block field treatment techniques (Az=0.37±0.16 with p-value=0.67 and Az=0.66±0.13 with p-value=0.19, respectively). There was not distinction in the development of ARSR observed between each of the treatment techniques (p-value>0.08). **Conclusions:** SSD was found to be a sensitivity factor to predict ARSR for the patient undergoing RT with 3D MLC and IMRT sliding window treatment. A larger SSD should decrease the risk of ARSR.

SU-FF-T-354

Penumbra Measurement with the Use of a 2D Pixel Ionization Chamber

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Purpose: To attest the accuracy of the penumbra measurement with the use of a 2D pixel ionization chamber. **Method and Materials:** Penumbra measurements were carried out for several clinical cases, treated with Intensity Modulated Radiation Therapy, with a pixel ionization chamber and with radiographic film as reference. The pixel chamber consists of a matrix 1020 detectors, each 4.5 mm diameter and 5 mm height at a pitch of 7.62 mm. Each of the 1020 ionization chambers was read out independently with no dead time. Standard radiographic films have been used, scanned with a pitch of 0.16 mm and 0.40 mm. Both detectors were

irradiated with 6 MV photon beams, using a linac equipped with a 120-leaves multileaf collimator. Measured dose profiles were fitted with a "Fermi-like" function: $f(x) = \frac{1}{1+e^{a(x-x_0)}}$ with x_0 and a as free parameters; the value for the penumbra could then be derived from the fit. The two sets of data were compared. **Results:** The data for the penumbra measured with the pixel chamber and the film for several IMRT fields show a strong linear correlation. This made it possible to correct the penumbra values obtained with the pixel ionization chamber to obtain a precise measurement even in a range well below the pixel dimensions. **Conclusion:** The 2D pixel ionization chamber has been shown to be able to measure the penumbra down to ~ 2mm with an accuracy of ± 0.6 mm. This device can then efficiently replace radiographic film in some QA procedures with a significative gain in time as it gives results in real-time and data are immediately available. **Conflict of Interest:** Research sponsored by MAESTRO, European project on Methods and Advanced Equipment for Simulation and Treatment in Radiation Oncology

SU-FF-T-355

Performance Evaluations of a Preemptive Approach in IMRT Planning

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Purpose: Preemptive Goal Programming (PGP) facilitates the use of soft-constraints in a hierarchical manner for solving complex inverse planning problems. It is a highly effective multicriteria strategy for IMRT planning. However, in order to ensure good numerical performance, a robust constrained optimization algorithm with a practical strategy for handling degeneracy is required. This study identifies cases when PGP introduces challenging problems that do not hold a conventional constraint qualification. Numerical performance for such problems is evaluated using nonlinear planning metrics (DVH, EUD, and NTCP). **Method and Materials:** PGP, as implemented in our in-house planning system, solves a series of nonlinear least-squares problems by a sequential quadratic programming (SQP) algorithm provided with precise Jacobians by an automatic differentiation algorithm. In the presence of constraint degeneracy, an elastic mode (feasibility bound relaxation) is used to ensure a positive step taken at all iterations. Dosimetric as well as numerical performance is evaluated for dose (or EUD) escalation cases with critical organ dose constraints. Reformulation of constraints is also studied as a potential way of reducing degeneracy in these problems. **Results:** Optimization levels involving strongly active constraints showed degeneracy near optimality, thus requiring use of the elastic mode for convergence. This mode exhibited robust convergence (typically <~100 iterations) for all IMRT cases studied. Highly nonlinear models (NTCP or EUD with high +/-powers) were handled well by SQP. A strategy of constraint reformulation showed a monotonic decrease in merit function value and its dosimetric performances were comparable to those without reformulation. **Conclusion:** The optimization task of escalating target dose is limited by binding dose constraints of OARs, which can also create degeneracy in PGP. This study shows SQP with an elastic mode exhibits a stable convergence using the dose-volume, EUD and NTCP metrics. Numerical performances can be further stabilized by reformulating degenerate constraints.

SU-FF-T-356

Permanent Prostate Implants: Dose to Critical Structures Inferior to the Prostate

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The basic goal of any radiation therapy is to maximize the dose to the tumor while minimizing dose to normal structure. With permanent prostate implants, treatment plans are developed to spare the urethra and the rectum. Post-implant evaluation shows that the actual implant does not mimic the plan primarily due to prostate swelling and source position shift either at the time of deposition or post implant. Dose indices have been developed to evaluate dose coverage to the implant. 90% prescription to the 100% of the prostate (V100) is considered an excellent implant. A good execution of the implant plan will still maintain a cooler urethra and low dose to the rectum. It is common to see under-dose in the base region of the prostate and seeds below the apex of the prostate. Sources below the apex of the prostate result in dose to the external sphincter, corpus cavernosum and internal pudendal artery. At our institution, we routinely obtain an MR for anatomic delineation and a CT for source localization 2 weeks after the implant. The datasets are registered based on mutual information techniques and dose to the normal tissue are reported. Fifteen patient entered in this study received a permanent implant to 145 Gy using I125 sources. The average volume of the MR prostate was 50.7cc. The average V100 was 90.5%. The average max dose to the right and left corpus cavernosum was 26.1(10.6) Gy and 28.1(12.4) Gy, respectively. The average max dose to the right and left pudendal arteries was 39.7(25.2) and 40.9(18.5) Gy, respectively. The average dose to 90% of the external sphincter was 132.1(44.9) Gy. With sufficient follow-up it is possible to correlate the dose to the vascular structures and their effect on erectile function, and dose to the external sphincter and the effect on urinary function.

SU-FF-T-357

Physical and Biological Characteristics of Megavoltage Grid Radiation Therapy

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Purpose: Dosimetric characteristics of a newly designed GRID block for megavoltage radiotherapy were investigated using TLD, film, and ionization chamber. Therapeutic advantage of this treatment modality was determined using a linear quadratic model in terms of treatment dose, GRID hole size, center-to-center spacing between the holes, and sensitivity of tissues to radiation. **Method and Materials:** Recently a newly redesigned GRID block has been introduced by Radiation Product Design, Inc. for different linear accelerators. Dosimetric characteristics (i.e. GRID output, dose profiles, and %DD) of three GRID blocks with different hole size and spacing were experimentally investigated. These GRID blocks were designed for a Varian 21EX linear accelerator. The measurements were performed using radiographic films and thermoluminescent dosimeters (TLDs) in Solid Water^{TM} phantom materials and an ionization chamber in water. The measured dose profiles were then utilized to evaluate the therapeutic advantage of the GRID therapy as a function of dose, grid hole size and spacing, and also radiosensitivity of tissues with a linear-quadratic (LQ) model. Therapeutic advantage of these GRID blocks was determined for a single fraction dose of up to 30 Gy. **Results:** Dosimetric characteristics of the GRID field were determined as a function of field size, beam energy, and Grid geometry. The results had shown that the therapeutic advantage of GRID increases by increasing the hole size, decreasing the spacing between the holes, and increasing the treatment dose. Moreover, the advantage of the GRID therapy was more pronounced for the radioresistant cells than radiosensitive cells. **Conclusion:** GRID radiotherapy exhibited a significant therapeutic advantage over the open field radiotherapy when the tumor cells were more radioresistant than normal cells. In addition, the therapeutic advantage of the GRID therapy is dependent on the treatment dose, GRID hole size and spacing between the holes.

SU-FF-T-358

PlanCheck: A System for Routine Clinical Comparison of IMRT Treatment Plans with Monte Carlo Recalculations

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Purpose: Current IMRT QA methods are cumbersome and are not comprehensive. The purpose of the PlanCheck dose recalculation system is to provide independent verification that MLC leaf-sequences generated by commercial treatment planning system will result in an acceptable dose. **Method and Materials:** The PlanCheck Beam Commissioning process was developed for medical linear accelerators and includes modeling of the photon energy spectra, off–axis softening, electron contamination, flattening filter and penumbra blurring. The Monte Carlo beam parameters are derived by fitting treatment planning dose in water and to the measured dose. The system will regenerate the dose for each treatment and for the

whole planned dose utilizing the Monte Carlo engine based on beam sequence DICOM/RTOG information imported into PlanCheck. The comparison metrics, including dose-volume histogram comparisons, report the validation quality and dose agreement. **Results:** Monte Carlo commissioning was tested for Varian Linear Accelerator (Clinac 2100) for 2x2 cm^2, 5x5 cm^2, 10x10 cm^2 and 20x20 cm^2 open fields in water for 6MV, 10MV and 18MV photon beam. The profiles and comparison results show good agreement for Eclipse (Varian) open field dose in water. The IMRT treatment plans from systems such as XiO (CMS), Eclipse (Varian) and Pinnacle (Phillips) were tested with Plancheck for dose agreement with Monte Carlo Dose and found to show adequate agreement. **Conclusion:** PlanCheck Monte Carlo calculations shows good overall agreement with treatment planning results except for regions with complex heterogeneities. Sun Nuclear Corporation is currently developing this product for intensive commercial use. The system dose engine is currently in process of integration with a 64-bit/16-node calculation cluster, which we expect will make the typical IMRT plan calculation time 30 minutes or less for the total planned 3D dose.

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SU-FF-T-360

Planning Strategies to Reduce Unnecessary Skin Dose in Head and Neck IMRT, Including Experimental Verification

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Purpose: To investigate IMRT planning techniques that reduce skin dose without adversely impacting important doses at depth and to experimentally confirm these findings.
Method and Materials: A semi-cylindrical phantom was constructed with catheters at 3, 6, 9 and 12mm depths, allowing micro-MOSFET dosimeters to be inserted to measure dose at multiple points on the surface and in the build-up region. Critical structures, a node-like CTV, and 2mm surface structure ('skin') were contoured on a CT image of the phantom with and without an immobilization mask. A PTV was generated by expanding the CTV 5mm in all directions up to the body contour; three modifications were then implemented, pulling back the PTV 0, 3 or 5mm from the body contour. Seven-field IMRT plans were created using Eclipse to maximize PTV coverage, with one of the following strategies: (1) aim for maximum 110% hotspot, 115% allowed, (2) maximum 105% hotspot, (3) maximum 105% hotspot and 50% of skin to get maximum 70% of prescribed dose, (4) 99% of PTV volume to receive 90-93% of prescribed dose, maximum 105% hotspot, and dose to skin structure minimized. All twelve PTV and planning strategy combinations were investigated, with and without immobilization mask. The plans were then delivered using a Varian 21Ex, and dose to skin and build-up region was measured.
Results: From highest to lowest skin dose, the planning strategies were (3), (4), (2), (1), with little dependence on the PTV expansion approach. Technique (3), however, showed a tendency to underdose tissues at depth.**Conclusion:** The best strategy to reduce unnecessary skin dose, while maintaining target dose, is to pull the PTV back 3-5mm from the skin surface, and plan such that PTV coverage is maximized, with 99% of PTV volume receiving 90-93% of prescribed dose, maximum 105% hotspot, and the skin structure dose minimized.

SU-FF-T-361

Planning Study of Intensity-Modulated and 3D Conformal Radiotherapy of Whole Pelvis Including Inguinal Lymphatics: Radiobiological Considerations for Designing New Fractionation Schemes

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Purpose: To examine the possibility of using "simultaneous integrated boost" intensity-modulated radiotherapy (SIB-IMRT), for the management of pelvic malignancies, with potential clinical advantage for simultaneous delivery of high doses to the primary disease and lower doses to the subclinical disease or electively treated regions.
Method and Materials: For this study, a sample patient diagnosed with anal cancer was randomly selected from our database. Four treatment plans were developed: (1) the 3D conformal plan for initial pelvis/inguinal node irradiation and subsequent conventional 3D boost to the primary tumor, (2) conventional 3D initial pelvis/inguinal node irradiation and subsequent IMRT boost plan, (3) Two-phase IMRT plan for initial pelvis/inguinal node irradiation and subsequent IMRT boost plan, (4) A single-phase SIB-IMRT plan to deliver simultaneous boost. DVHs for the target volumes were transformed into equivalent uniform dose (EUD) using the LQ model to evaluate relative merits of these plans using tumor control probability (TCP), and normal tissue complication probability (NTCP) for normal tissues.
Results: We have found that dose distributions for SIB-IMRT are similar in conformality to dose distributions when IMRT is divided into a large-field phase and a boost phase. As shown in Fig. 1(a-d), both techniques produce significantly superior dose distributions compared to those obtained with 3DCRT as well as to dose distributions obtained using conventional beams for the large-field phase followed by IMRT boost phase. We also found that normal tissues outside the target volume receive significantly lower dose due to higher dose conformality of IMRT plans (Table 1). **Conclusions:** SIB-IMRT offers unique ability to produce highly conformal dose distributions with better sparing of organs at risk, with more efficient delivery, and shorter treatment duration. This new modality also facilitates the prospect of dose escalation to highly advanced tumors for better radiobiological effectiveness potentially leading to improved outcome.

SU-FF-T-362

PLanUNC as An Open-Source Radiotherapy Planning System for Research and Education

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Purpose: PLanUNC is a radiotherapy planning software package that has been under development and clinical use at the University of North Carolina for approximately 20 years. Under a joint grant from the NCRR and NCI (R01 RR 018615), PLanUNC has been documented, commented, and prepared for distribution as a freely available open-source treatment planning tool for use as an adaptable and common platform for radiotherapy research. **Method and Materials:** The software and source code have been made available to qualifying users through a web portal located at http://planunc.radonc.unc.edu. Licenses for PLanUNC are available without fee to institutions, departments, and other facilities engaged in research and education involving radiation therapy. **Results:** Recent research milestones demonstrating the extensibility and increasing utility of PLanUNC include tools for 4D planning, interfaces with ITK segmentation and registration tools, daily correction of patient positioning, and interfaces with a variety of Monte Carlo dose engines. PLanUNC is currently supported for Linux and Windows operating systems, but has been successfully compiled on Alpha, Macintosh, Solaris, and other platforms. **Conclusion:** Licensed users will have access to PLanUNC source code, user and development documentation, annual training workshops, and limited support from UNC and the PLanUNC research community. PLanUNC is distributed as source code, making it customizable and extensible to meet the needs of a diverse range of research applications.

SU-FF-T-363

Plastic Scintillator Preparation and Coupling in Scintillation Dosimetry

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Introduction: One way to improve the performance of scintillation dosimeters is to increase the light collection efficiency at the coupling interfaces of the detector. The present work present a detailed study of scintillating fiber preparation and their coupling to clear optical fibers in order to minimize light losses and to increase the light signal collected.
Methods and Materials: Surface polishing with aluminum oxide sheets, reflector coating with MgO and use of eight different coupling agents (air, three optical gels, optical curing, ultraviolet curing, cyanoacrylate glue and acetone) were considered. For each coupling technique, ten samples were

prepared. The procedure followed was: first, both the scintillating fiber and the optical fiber were cut. Then, each extremity was cleaned and polished. Finally the coupling between the scintillating fiber and the optical fiber was made either in a polyethylene cylinder or in a V-grooved support depending on the kind of coupling agent used. To produce a large quantity of light, a UV lamp was used to stimulate scintillation. **Results:** A typical series of similar couplings showed a standard deviation equal to 10 %. This can be explained by the difference in the surface quality and the alignment of the scintillating fiber over the optical fiber. Surface polishing improves the light collection by approximately 65 % and a reflective coating on the distal end of the scintillator by approximately 40 %. For the coupling agents, the best results were obtained using an optical gel. **Conclusion:** In plastic scintillation dosimetry, there is usually a compromise to be made between the spatial resolution of the probe (i.e. its size) and the total signal collected by the photodetector. Since a large amount of the light produced inside the scintillator is usually lost, a better collection efficiency will result in improved spatial resolution for a given signal intensity.

SU-FF-T-364

Positioning in Cranial Stereotactic Radiotherapy: Anatomical Points Vs. Full 3D Transformation

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Purpose: Some commercial IGRT systems do not have yet proper software tools for stereotactic localization. We evaluated two different isocenter realignment techniques for fractionated cranial treatments (previously presented). The goal of this report is to compare these two techniques and quantify the importance of using isocenter shifts derived from full 3D alignments. **Method and Materials:** A comparison study was carried out based on a total of 26 treatments (7 patients localized with the GTC relocatable frame; total of 41 isocenters,). Prior to each treatment a scan was acquired with Primatom CT-on-rails system (Siemens, Concord, CA), and the scan was registered by the treatment planning system (Radionics, Boston, MA). Three anatomical control points (ACP) were used for realignment. First, the control points were identified by a physician, their coordinates were recorded and a daily shift was calculated as an average value of the control point shifts (ACP method). Then using 3D transformation, we separately calculated the shifts of the control points and the shifts of the isocenters (3D alignment method). Statistical analysis was performed separately for (1) control points shifts and (2) isocenter shifts. **Results:** As expected, the differences between the two methods in control point shifts (0.6 to 0.9 mm, one SD) correlated with the root-mean-square of the individual uncertainties of each method. When comparing isocenter shifts, we found greater random (0.9 to 1.1 mm) and systematic differences between the methods. The increased errors observed in isocenter shift comparison were due to several peripheral isocenters, for which the ACP method failed. The maximum discrepancies observed were from 3 to 5 mm. **Conclusion:** The results from this study show that when using the GTC relocatable frame a physician can use the ACP method for patient alignment, provided that the treated isocenter is close to at least one point or between points.

SU-FF-T-365

Practical Reconstruction Method for 3D CT-Based Brachytherapy with Shielded Colpostats

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Introduction and purpose.- The most extended worldwide HDR and PDR afterloading machines are from Nucletron, using the Plato Treatment Planning System (TPS) to perform the clinical dosimetry. The Fletcher-Williamson (FW) vaginal colpostat applicators are widely used with these machines, they are made of a very dense material (densimet-17) which allows shielding up to 50% of the dose. Almost all the TPS have incorporated the CT-Based Brachytherapy (BT), in which the CT catheters and applicators reconstruction is based on contiguous CT transverse slices where the user points the catheter position. The problem with these applicators is the production of artefacts that makes the reconstruction impracticable. CT Orthogonal Scout Views or scanograms (OSV) to reconstruct sources in Brachytherapy, have been well described (Meli 1995, Yue 1999). The purpose of this work is to incorporate the OSV reconstruction method to the PLATO TPS. **Material and methods.-** We have taken profit of the fact that the TPS keeps the CT coordinates. A spread sheet has been developed to reconstruct the FW from OSV. The advantage of this method is that the obtained catheter coordinates are referred to the CT coordinates. The obtained OSV points are introduced on TPS as markers in the contouring routine because the TPS does not allow direct catheter coordinate input. Even in the catheter reconstruction routine it is easy to follow the markers to recognize the catheter within the FW. Some phantoms have been built with pellets to check the procedure accuracy. **Results: .-** The global OSV accuracy obtained with the phantom tests is estimated to be within 1 mm. Significant step by step examples will be shown. **Conclusions.-** The method is easy and feasible for Plato TPS users, and not only for shielded colpostats but also for implants quasi parallel to the CT slices as breast implant.

SU-FF-T-366

Prediction of Collimator Scatter Factor and Phantom Scatter Factor for Kilovoltage X-Ray Radiation Fields

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Purpose: Kilovoltage x-ray tube therapy beams are used for treatment of keloids and localized superficial malignancies. The purpose of this work is to predict the collimator scatter factor and phantom scatter factor for kilovoltage x-ray radiation fields. **Method and Materials:** The radiation field is defined by a variable collimator with or without lead sheets on the patient's skin. Measurement and prediction were done at tube potentials of 60, 100, 120 and 250 kVp. Our approach uses three different sets of field types: square fields defined by the collimator and square and circular fields defined by lead sheets. Two calculation methods are employed: the equivalent field and Clarkson's method. Calculation and measurement were also done for rectangular and irregular shape fields. The relative difference between predicted and measured values is given in the form of percentage error as follows: 100% (predicted value – measured value) / (measured value). **Results:** The error ranges between calculated and measured collimator scatter factors for the equivalent field method and Clarkson's method are, respectively, 2.41% and 1.84%. All errors are within ±1% with Clarkson's method. The results show that Clarkson's method is more accurate at predicting collimator scatter factors. The error ranges between calculated and measured phantom scatter factors for the equivalent field method and Clarkson's method are, respectively, 6.3% and 3.5%. The spread of errors is narrower for Clarkson's method. Clarkson's method is therefore more accurate at predicting phantom scatter factors. **Conclusion:** Using the measured data for square fields defined by the collimator together with Clarkson's method is recommended. The implementation of this method requires a minimum number of measurements which are acquired during the commissioning of the unit and can be applied in dose calculation for a variety of field shapes and sizes.

SU-FF-T-369

Propagation of Linac Output and Fluence Discretization Error to Dose Distributions in IMRT

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Purpose: Linac output variation and the fluence discretization from MLC leaf sequencing are sources of IMRT delivery error. We investigate a theory describing the propagation of fluence errors to dose distributions. **Method and Materials:** We assume that the fluence from each beam port is the planned fluence plus a gantry angle dependent error. We assume linac output variation contributes to systematic and random error whereas fluence discretization error is purely random. Expressions for the random and systematic dose error distributions were derived with standard error propagation theory. We investigated hepatocellular carcinoma (HCC) and prostate cases planned with step-and-shoot IMRT and tomotherapy. Linac output errors were estimated from measurements from a linac with a malfunctioning magnetron, thus representing higher-than-normal output errors. The maximum relative random and systematic linac output errors were both around 2%. **Results:** For both patients and both modalities, the relative dose error in the PTV due to systematic linac output variations was around 1% and the random component was negligible. The dose error in the PTV due to fluence discretization was between 0.1% and 0.2% for

tomotherapy and about 1% for step-and-shoot. The relative dose error threshold such that 90% of the voxels in the PTV had a 90% chance of error less than the threshold was 1.5% for step-and-shoot and 0.5% for tomotherapy. **Conclusions:** The relative random dose error at a point decreases as the inverse square root of the number of beams that affect that point, making the relative random dose error orders of magnitude lower than the relative systematic error. Systematic dose error changes little with the number of beams used in the treatment since it is not propagated in quadrature. The dose errors from the malfunctioning magnetron had little effect on the treatment. **Conflict of Interest:** TR Mackie has financial interest in TomoTherapy Inc.

SU-FF-T-370

Properties of the Iso-NTCP Envelope

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Purpose: To analytically investigate a property of the integral dose-volume histogram (DVH) space. **Method and Materials:** A curve called an α-iso-NTCP envelope is constructed by connecting points belonging to step-like integral DVHs each corresponding to partial organ homogeneous irradiation of relative volumes v_α to dose levels D_α such that the resulting NTCP is in all cases α %. The two subspaces into which the envelope divides the DVH space are analytically explored through comparing the values of the equivalent uniform doses (EUDs) corresponding to the different DVHs and using the fact that NTCP is a monotonic function of EUD as well as the monotonic nature of the integral DVH itself. **Results:** It is theoretically proven that any DVH passing through a point (D_α, v_α) from the α-iso-NTCP envelope, i.e. any DVH that crosses or is tangential to the envelope, will result in an $NTCP \geq \alpha\%$, the equality being valid only for the step-like DVH corresponding to the partial organ homogeneous irradiation of v_α to D_α,. Thus, it is proven that any DVH that at least partially lies above the envelope result in $NTCP > \alpha\%$. For some of the DVHs lying under the envelope, e.g. those that are tangential to the envelope, it is also true that the resulting $NTCP > \alpha\%$. However, it was numerically demonstrated elsewhere[1] that there exist DVHs lying entirely in the lower subspace that result in $NTCP < \alpha\%$. **Conclusion:** Since there is a chance that a DVH lying under the α-iso-NTCP envelope will result in $NTCP < \alpha\%$, it would therefore be preferable in the treatment optimization process to seek solutions for DVHs lying entirely under an iso-NTCP envelope.

1. C. Schinkel-Ranger, P. Stavrev, N. Stavreva, and B. G. Fallone. *"A theoretical approach to the problem of dose-volume constraint estimation and their impact on the dose-volume histogram selection,"* submitted to Medical Physics, 2006.

SU-FF-T-371

Properties of Unflattened Photon Beams Shaped by a Multi Leaf Collimator

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Purpose: Several studies have shown that removal of the flattening filter from the treatment head of a clinical accelerator increases the dose rate and changes the lateral profile in radiation therapy with photons. However, the multi-leaf collimator (MLC) used to shape the field was not taken into consideration in these studies. We therefore investigated the effect of the MLC on flattened and unflattened beams. **Method and Materials:** To do this, we performed measurements on a Varian Clinac 21EX and MCNPX Monte Carlo simulations to analyze the physical properties of the photon beam. We compared lateral profiles, depth dose curves, MLC leakages, and total scatter factors for two energies (6 MV and 18 MV) of MLC-shaped fields and jaw-shaped fields. **Results:** Our study showed that flattening filter–free beams shaped by an MLC differ from the jaw-shaped beams. Similar differences were also observed for flattened beams. Although both collimating methods produced identical depth dose curves, the penumbra size and the MLC leakage were reduced in the softer, unflattened beam and the total scatter factors showed less field size dependence. **Conclusion:** Our findings suggest that, when commissioning a treatment-planning system, one should use the profiles of the MLC-shaped fields in addition to profiles of the jaw-shaped fields.

SU-FF-T-373

Quality Assurance of Individual Segments of Step-And-Shoot IMRT

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Purpose: Absolute point dose measurements as part of the quality assurance of step-and-shoot intensity modulated radiation therapy (IMRT) often reveales unexpected deviations. This study investigates the feasibility of IMRT-QA of individual segments to explain these deviations, and the efficacy of different evaluation methods. **Method and Materials:** The dose in a small volume around the point of interest (POI) was calculated for the individual segments of an IMRT plan for which a software script was added to our treatment planning system (Pinnacle[3] 7.6c, Philips). Furthermore, two input parameters for analysis of the measurements, i.e. the dose per monitor unit (D/MU) and the maximum dose gradient (δD/δr), were calculated for each segment. A software application was developed for automated data acquistion and analysis. The analysis was carried out either disregarding measurement data with a low confidence level (δD/δr or D/MU outside a critical range), or using γ-evaluation. **Results:** IMRT-QA was performed for 10 prostate and 5 head and neck patients. We found significantly higher deviations for segments at which the detector turned out to be located within the penumbra, which was consistent with $0.15 < D/MU < 0.55$ cGy/MU, or $\delta D/\delta r > 0.25$ cGy/mm. When these data were filtered out, the total dose deviation ranged from -2% to 3% (not filtered: -5% to 5%). However, only 78% of the fraction dose was verified on average due to filtering. When γ-evaluation was used, 93% of the fraction dose was within acceptance criteria (2.5% D_{segm}; 2.5mm) on average. Datapoints outside these acceptance criteria were predominantly related to measurements behind jaws or leafs ($D/MU < 0.15$). **Conclusion:** IMRT-QA of individual segments revealed that penumbral ionometric uncertainty is the main cause of deviations in overall IMRT-QA. This method is feasible in daily clinical routine and provides more insight in deviations between measurements and calculations.

SU-FF-T-374

Quality Assurance of the On-Board Imager and Cone-Beam Computed Tomography Systems

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Purpose: To develop a comprehensive quality assurance (QA) program for the On-Board Imager (OBI) used for patient positioning verification and to present the results of QA tests over extended periods from multiple institutions. Radiographic and cone-beam computed tomography (CBCT) mode have been evaluated. **Methods and Materials:** The QA program consists of three parts; (1) safety and functionality (2) geometry and (3) image quality. Safety checks evaluate the functionality of collision interlocks and audible alarms. Functional QA checks the flow of clinical operation during tube warm-up. Geometry QA checks geometrical accuracy and variation of the OBI/CBCT and hardware/software. Image quality QA includes measurements to monitor accuracy and stability of the OBI/CBCT imaging system. **Results:** All test items show stable functionality for safety and functional QA on a daily bases. The precision of arm positioning is very high with variation of 1mm and average accuracy of < 1mm over 8 months. The average accuracy of the isocenter and couch shift is < 1mm with variation of 1mm over 11 months. Arm position was performed when the results were > 2 mm. Results of geometry QA have been stable within tolerances through the test periods. All tests for Image quality tests also show consistent results within tolerances. **Conclusion:** We have developed a practical yet comprehensive set of QA tests for the OBI system. Data collected for these tests over the extended period show that the OBI system has mechanical reliability and stable image quality. Nevertheless, the tests were useful in detecting performance deficits in the OBI system that needed recalibration. After accumulating enough experience and confidence on stability and accuracy, some institutions have reduced the frequency of QA checks.

However, it is important that all tests are performed on a regular basis within a suggested period to establish a guideline.

SU-FF-T-375

Quality Contra Complexity in IVD. A Comparative Study Between Three Semiconductor Detectors

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Semiconductor detectors have frequently been used in vivo dosimetry (IVD) to confirm the dose given to a patient in external radiotherapy, due to the high mechanical stability, small size, high signal and no need of external bias. As it is important that the complexity of these measurements should be as low as possible, semiconductor detectors from three different manufactures have been compared with respect to the need of correction factors, where effects of radiation damage has been studied.

Detectors from Sun Nuclear (SN), PTW and Scanditronix Wellhöfer (SW) have been investigated in 15 MV x-rays. The sensitivity drop, dose rate linearity, the sensitivity variation with temperature (SVWT) and "dark current" have been studied after different doses of irradiation. Parameters, which are related to the mechanical construction, the field size and directional dependence have also been studied.

It was shown that the SW and SN detectors showed small variations in the sensitivity drop and the linearity properties did not change after moderate doses, about 1 kGy of 15 MV x-rays. PTW, however, showed a three times larger sensitivity drop and an increasingly non-linear response. The SVWT was stable for the SW, 0,2% per centigrade, and for the SN detectors, 0,5 % respectively. The PTW detector showed a low value in the beginning, but increased after irradiation. Also the "dark current" changed after irradiation, and was in favour for the SW detector.

The directional dependence was about the same for all detectors, but the field size dependence deviated for the PTW detector.

To obtain an accuracy better than 1,5% in each parameter the complexity is rather low for the SW and SN, except for the temperature dependence for SN. It is, however, rather complicated for the PTW detector, as large corrections must be applied for some parameters.

"Research sponsored by Scanditronix-Wellhoepher corporation."

SU-FF-T-376

Radiation Leakage From Acrylic Electron Cones for An Intraoperative Therapy Linear Accelerator

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Purpose: To determine the radiation leakage at the outer wall of intraoperative radiation treatment (IORT) cones. **Method and Materials:** The leakage radiation dose for the acrylic IORT cone system attached with a Clinac 2100C of Varian was studied. Radiographic films were wrapped around the cone wall to locate the area of the high radiation leakage according to the optical density of the films. Then the leakage doses at the cone wall with high optical density starting from the distance of 0 – 8 cm upward from the cone end and also the dose at the depth of maximum dose were measured by using TLD-700 rods type in solid water phantoms. The measurement were made for 4.5, 6.4, 8.3, and 9.5 cm diameter cones (both flat and bevel ends) with 6, 12 and 20 MeV electron beams. **Results:** The leakage dose as the percentage of the maximum dose at the central axis of the beam tended to increase with the energy and cone size except the 8.2 cm cone at 20 MeV which showed more leakage dose than the value of 9.5 cm diameter for both flat and bevel ends at the distance 8 cm from the cone end. Both flat and bevel cones presented the minimum and maximum leakage radiation with the same cone size (4.5 cm for minimum and 8.2 cm for the maximum) and the distance from the cone end (at the cone end for minimum and 8 cm for maximum). Their values were very close with the minimum of 4.37% and 4.92% and the maximum of 22.94% and 23.10% for flat and bevel end cones respectively. **Conclusions:** The tolerance dose of the normal tissue involved in each treatment should be considered together with the maximum leakage dose for the cone size and energy used in the treatment.

SU-FF-T-377

Radiation Shielding Calculations and Measurement for a Helical TomoTherapy Unit in An Existing Treatment Room

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Purpose: To quantitatively evaluate the appropriateness of an existing LINAC treatment room shielding for a Helical TomoTherapy (HT) (TomoTherapy Inc., Madison, WI, USA) unit operating under typical radiation oncology department workload. Methods and Materials: A treatment room previously designed for a Varian Clinac 600C LINAC was considered for housing a HT unit. Shielding calculations for primary and secondary radiations (leakage and scatter) were performed to evaluate whether additional shielding was needed. A typical radiation oncology patient load (40,000 rem/wk) was used. Use factors were derived and calculated based on unique HT rotational beam delivery. Leakage and scatter was included in the calculation based on corresponding measurements as documented by TomoTherapy Inc. After installation of the HT unit, a radiation survey was performed to verify calculation results. **Results:** Calculations showed that a typical 600C shielding design is generally sufficient for a HT unit for typical workloads. However, in our situation, additional shielding was required for a small area of one wall due to positioning of the HT unit isocenter. The radiation survey carried out after HT installation showed all barrier calculation locations satisfied radiation safety requirements. **Conclusions:** It is recognized that leakage radiation levels for IMRT treatments on HT are increased significantly due to increased beam-on time to deliver modulated fields. This investigation showed that a typical 6 MV room design provides adequate shielding barriers for a HT unit operating under typical radiation oncology workload in most cases. Under some circumstances, such as placement of unit in the room away from original isocenter design, extra shielding materials may be required. A caution is thus needed for institutions considering installing new HT unit within an existing LINAC treatment room.

SU-FF-T-378

Radiation Transport Software for Medical Physics Studies

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Purpose: To present a summary of radiation transport software for medical physics applications. **Method and Materials:** The Radiation Safety Information Computational Center (RSICC), a center at Oak Ridge National Laboratory (ORNL), is the Department of Energy software center for radiation transport and safety software. The center houses over 1600 software packages and nuclear cross section data of importance to nuclear science applications. The different software packages have been applied to the following topics:

- Dosimetry calculations for radiation therapy
- Treatment planning in radiation oncology
- Design of photon and secondary neutron shielding for therapy rooms
- Evaluating and estimating patient and staff radiation dose
- Electron beam transport and energy deposition
- Secondary neutron and gamma transport and energy deposition
- Cancer brachytherapy dosimetry
- Medical diagnostic imaging applications, including SPECT, PET, and x-ray imaging
- Error evaluations for accelerator particle delivery systems
- Modalities of treatment and exploration of alternatives
- Licensing and safety analysis for medical radiation facilities
- Medical diagnostics and therapy

Examples of software in the RSICC collection include MCNP/MCNPX, ITS, ANISN, TORT, EGS4, PARTISN, SERA, and PENELOPE. There are other software packages (not available through RSICC), which have been applied to the above topics – for example, PENTRAN, A3MCNP, ATTILA, COMET, EGSnrc, TransMED, EVENT, FLUKA, PEREGRINE. **Results:** Studies on selected software is presented, particularly on the above applications. **Conclusion:** As the field of medical physics advances, computer software technology continues on the road to improvement and

efficiency. **Conflict of Interest:** Work was supported by the Department of Energy under contract DE-AC05-00OR22725.

SU-FF-T-379

Radiochromic Film Dosimetry for a New Type of I-125 Seed: Determination of TG43 Parameters

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Purpose: A new prototype of I-125 seed was studied using radiochromic EBT film in solid water for the dose distributions from 0.06cm out to 5cm. The high activity seed was designed for intravascular brachytherapy of lesions in peripheral arteries. The active source core was produced with Xenon ion implantation into a solid quartz core (without silver marker) and then encapsulated in titanium to form a sealed source.
Materials and methods: A multiple film technique was employed. Each film (EBT lot #35076) was in contact geometry with the seed at the center of a solid water phantom, 30x30x20 cm. Totally 46 films were separately exposed to 12 seeds, with the product of activity and exposure time between 8 and 4910 mCi-hr. The seed activity ranged from 12.5 to 2.4 mCi during the experimental runs. 30 calibration films were exposed to one seed at 0.5 cm above or below the seed. All experimental, calibration and background films were scanned (pixel resolution 0.2mm) using a PeC CCD100 densitometer, with red and green light sources at least one day after exposures. Conversion from optical densities to doses was achieved based on the calibration curve established for each light source used in scanning. The 2-d dose values in cylindrical coordinates were converted to polar coordinates, and the TG43 parameters were generated. **Results:** The radial dose function and anisotropy function were plotted. Compared with the Implant Sciences model 3500 seed, the anisotropy function values are similar, while the radial dose function values (at distances > 1cm) are higher, possibly due to the absence of silver fluorescent x-rays. An interim value of dose rate constant was determined. **Conclusion:** TG43 parameters for a new type of high activity I-125 seed have been obtained using radiochromic EBT film for distances from 0.06 to 5 cm in solid water phantom.

SU-FF-T-380

Radiological Dependence of Electronic Brachytherapy Simulation On Input Parameters

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Purpose: In comparison to ^{125}I or ^{192}Ir, characterization of dose rate distributions from electronic brachytherapy is subject to the additional challenge of unforeseen photon energy spectra. Towards simulating photon energy spectra and resultant dose rate distribution, Monte Carlo investigators first generate electrons which bombard the x-ray tube anode and subsequently create photons via bremsstrahlung. Modeling techniques for this endeavor are largely unexplored. Therefore, sensitivities of spectra and dose rate distributions were assessed through varying modeling parameters for the Xoft Axxent x-ray source. **Materials & Methods:** MCNP5 was used to simulate photon spectra and dose rate distributions, with comparisons to experimental measurements (PTW model 34013 chamber in liquid water) for $1<r\leq 7$ cm and $0°\leq \theta \leq 150°$ with simulations covering $0.3 \leq r \leq 15$ cm and all available angles. The following source modeling parameters were evaluated for impact on in-water spectra and dose: electron beam radius (R), electron beam annularity (R') like a doughnut, and anode film thickness (t). Since simulations of electron:photon transport are inefficient in comparison to Monte Carlo modeling of radionuclides, MCNP variance reduction techniques such as cell importances (IMP), electron cutoff energies (PHYS:E), high-energy biasing of bremsstrahlung spectrum (BBREM), and bremsstrahlung photon multiplicity (BNUM) were assessed. **Results:** Due to the complex anode shape, $F(r,\theta)$ was highly-dependent on R, varying a factor of 2 when changing R from 0 to 0.084 cm. This effect was more pronounced when varying R' due to less radial volume averaging. Through comparison with experimental measurements, the optimal electron beam shape had the largest spot size which could fit within the anode and no annularity; it was a uniform pencil beam. Altering MCNP variance reduction techniques did not significantly alter results, but greatly hastened simulation efficiency. **Conflict of Interest:** Research was sponsored in part by Xoft, Inc.

SU-FF-T-381

Real-Time Treatment Planning System for Prostate Photodynamic Therapy

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Purpose: To develop a real-time treatment planning system for prostate photodynamic therapy (PDT). **Method and Materials:** A real-time treatment planning system has been developed for prostate PDT, which is composed of two sub-systems, i.e., image acquisition and light fluence rate calculation engine. The whole system is built in a personal computer. The image acquisition is implemented using an image frame grabber (DT-3120, Data Translation, Inc., MA) to acquire ultrasound images from a transrectal ultrasound unit in real time during a treatment. The software converts information about the organ geometries and the actual locations of the light sources on a template with 0.5-cm grids. These data are then input into the calculation system for prediction of light fluence rate distribution. The three-dimensional (3D) geometry of the prostate and the actual source arrangements are reconstructed and are used in the calculation, which takes into account the effect of optical heterogeneity. Treatment planning is accomplished with the prediction of 3D light fluence rate distribution. **Results:** The system has been tested in experiments. In a phantom experiment, transrectal ultrasound images of the prostate phantom during treatment were acquired and the actual locations of the linear sources were recorded. The geometry of the phantom was reconstructed and light fluence rate was calculated in the geometry with the accurate source locations. The capability of calculating light fluence rate distribution in a heterogeneous phenomenon was tested in a patient prostate. The reconstructed prostate geometry, actual source strengths, and measured heterogeneous optical properties, were used in the calculation. The predicted light fluence rate distribution showed the effect of heterogeneous distribution of optical properties. **Conclusion:** The real-time treatment planning system provides an efficient tool for prostate PDT, which improves accuracy in treatment planning.

SU-FF-T-382

Reduction of Total Body Exposure in Breast Radiotherapy Using Breast IMRT Or Virtual Wedge - Importance in the Prevention of the Leukemia in Combined Chemo-Radiation Regimens for Breast Cancer

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Purpose: The reported risk of leukemia following adjuvant radiotherapy for breast cancer has been reported to be low. However, two recent publications demonstrated that patients receiving combined high-dose anthracycline chemotherapy and breast radiation as part of their adjuvant treatment have a significant increased rate of secondary leukemia above 1.3%. Radiation was found to be an independent factor for the development of leukemia by a factor 2.38. This study aimed at evaluating the total body radiation exposure during breast radiotherapy and to characterize the factors associated with an increased exposure and more particularly the method of compensation technique. **Patients and Methods:** In a prospective cohort of 120 women, radiation measurements were taken at the time of adjuvant breast radiotherapy using TLD's placed on the contralateral breast, on the anterior abdomen, on the back, and on the contralateral ankle. Multiple regression analysis was performed to analyze patient and treatment factors associated with the amount of scatter radiation exposure. **Results:** For standard 50Gy breast radiotherapy, the minimal dose received by abdominal organs is on average 0.45Gy, ranging from 0.06 to 1.55Gy. The use of physical wedges as a compensation technique was the most significant factor associated with increased scattered dose ($p<0.001$), resulting in approximately three times more exposure compared to breast IMRT and dynamic wedge. **Conclusions:** The amount of radiation that is scattered to a patient's body is of a magnitude that has been observed to be associated with excess of leukemia in previous studies. In accordance with the As Low As Reasonably Achievable (ALARA) principle we recommend using only breast IMRT or virtual wedging instead of physical wedging for the radiotherapy of breast cancer patients receiving also high-dose anthracycline chemotherapy.

SU-FF-T-383

Regularization and the L-Curve for Inverse Planning Based On Equivalent Uniform Dose

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Purpose: In the dose optimization based on equivalent uniform dose (EUD), a single dose value is assigned to PTV or organ at risk. Obviously, this optimization problem is poorly defined – there is an unlimited number of nonuniform dose distributions (and, correspondingly, beam intensity functions) which will satisfy the EUD-based objective function. Together with the ill-posedness of the underlying integral equation, this may present a challenging mathematical problem. We propose an objective function for the EUD-based inverse planning which can solve this problem and produce stable and accurate numerical solutions. **Method and Materials:** We apply to EUD-based inverse treatment planning a variational regularization technique which was previously studied for the least squares dose optimization. The regularization parameter is found using the L-curve method which is based on minimization of the residual norm and the smoothing norm of beam intensity functions. The optimization technique is applied to the prostate cancer treatment. **Results:** We have compared inverse treatment planning with the standard least squares objective function and an EUD-based objective function. The dose distributions obtained from EUD-based optimization are extremely nonuniform with significant hot spots in the PTV. We have applied to the EUD-based optimization the variational regularization technique with the L-curve method for determining an optimal value of the regularization parameter. We demonstrate that the regularization method decreases dose variance and mean dose in the PTV while keeping EUD of the same value. The regularized dose distribution is stable and uniform in the PTV. **Conclusion:** Inclusion of a variational regularization technique into the EUD-based dose optimization produces robust dose distributions and beam intensity functions without deterioration of optimization accuracy.

SU-FF-T-384

Reliable Radiation Dosimetry for Acquiring Beam Data for a 6 MV Linac Based Stereotactic Radiosurgery

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Purpose: To evaluate the reliability of the dosimetry systems available at our institution in the measurement of beam data for 6 MV linac based stereotactic radiosurgery. **Method and Materials:** The measurements of total scatter factor (S_t), tissue maximum ratio (TMR) were made by using X-Omat V films, IC03, IC10, and a PTW Markus chambers . Only the films, IC03 and IC10 were employed in off axis ratio (OAR) measurements. Eight collimators with 10 to 50 mm diameters were involved in all measurements. **Results:** The TMR values measured by IC10 and Markus were agreeable within 2% for the collimators of 20 to 50 mm . The TMR values determined by all detectors for the collimators smaller than 20 mm may not be accurate enough for clinical use. The S_t values determined by all detectors with field sizes equal to or greater than 30 mm agreed within 2%. Markus and IC10 showed very closed values of S_t within 0.2%. For all collimators, the values of IC03 and film were about 1% less than the ones of Markus, and IC10. With the collimators of less than 25 mm, film presented the highest S_t values but Markus gave the highest values for the larger collimators. Film showed higher values of off axis ratios inside the beam area than IC10 and IC03 for all collimators. Comparisons of S_t **Conclusions:** From our study, it is concluded that the TMR values for 10 mm collimator should be measured by IC03 but the for larger collimators, IC10 is preferred. Among our detectors, film is the best one for the measurements of OAR for all collimators and S_t for the two small collimators (10 to 20 mm), with the larger collimators, Markus chamber should be used.

SU-FF-T-385

Reproducibility of the Optical CT-Based Polymer Gel Dosimetry

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Purpose: To study the reproducibility of the reconstructed dose distributions from optical CT scanning of polymer gel dosimeters with variation of time between irradiation and scanning using phantoms of the same and different geometry. **Method and Materials:** The commercial BANG®3 polymer gels from the same batch were housed in cylindrical phantoms of 3 types: a) PET bottles of 15 cm diameter and 20 cm height; b) Barex cylinders of 17 cm diameter and 15 cm height; c) Acrylic cylinders of 25 cm diameter and 25 cm height. Four PET and Acrylic gel phantoms were irradiated with a 5 field IMRT and a 3DCRT once each. Six Barex cylinders were irradiated with the same IMRT and 3DCRT plans three times each. One additional Barex gel phantom was irradiated with a 6 cm x 6cm, 12 MeV electron field for calibration purpose.

The gel phantoms were scanned using the OCTOPUS™ optical scanner one day after irradiation. One Barex phantom irradiated with IMRT fields was scanned 1 and 8 weeks later. All reconstructed images were calibrated using the dose response curve from the electron field irradiation. Root mean square of the pixel dose differences in a cylindrical region of 10 cm diameter and 10 cm height were compared for each pair of phantoms irradiated with the same plan. **Results:** The reconstructed dose distributions from scanning the same IMRT gel phantom 8 weeks apart change less than 1%. The root mean square dose difference among the 3 different kinds of phantoms irradiated with the IMRT and 3DCRT plans are all less than 3%. **Conclusion:** The optical CT-based polymer gel dosimetry is reproducible within the experimental uncertainty (3%) when different gel phantoms are irradiated and scanned at different time after irradiation.

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SU-FF-T-386

Respiratory Gating in the Treatment of Liver Tumors

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Purpose: To determine if respiratory gated radiotherapy is feasible for the treatment of liver tumors. **Method and Materials:** The patient was a 70 year-old woman with metastatic liver cancer. We used the RPM system (Varian Medical Systems) to track the respiratory cycle of the patient and gate the beam at the end of the respiratory cycle. Three implanted gold fiducials were used for daily patient positioning with AP and Lateral electronic portal images. The fiducials were also used to verify the location of the tumor during treatment. Prior to the initial treatment, the patient underwent a mock treatment in which a series of portal images were taken to verify the respiratory cycle correlated with the position of the tumor at the end of expiration. **Results:** The patient's mock treatment was successful, with nearly all fiducial locations lying within a sphere of 2.5 mm. Analysis of the data obtained over the course of treatment (~600 data points) showed that 95% of the fiducial locations stayed within a sphere of about 7 mm. The uncertainty due to set-up was ±4.6 mm, while the precision in the gating window was ±2.2 mm. **Conclusion:** The location of the liver tumor was well reproduced throughout the course of treatment. Our results suggest that we can use respiration to successfully track the motion of a liver tumor and gate the beam at the end of the respiratory cycle.

SU-FF-T-387

Rotational Total Skin Electron Irradiation Using a Commercially Available Linear Accelerator with a High Dose Rate Total Body Electron Mode

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Purpose: During the past 25 years, 185 patients have been treated with a rotational total skin electron irradiation (RTSEI) technique in our center. To modernize the technique we recently transferred it from a linac (Varian Clinac-18) with a custom modified beam line to a linac (Varian 21EX) with a commercially available electron mode intended for total skin electron irradiation. Methods and Materials: The new technique uses a "high dose rate" mode and a "high dose per Monitor Unit" mode in conjunction with a custom-made flattening filter to produce a uniform beam at an extended SSD of 378 cm. The accessory tray holds the custom-made flattening filter and automatically selects the beam energy (6 MeV) and high dose rate (888 MU/min) while moving the collimators to the maximum 40 x 40 cm^2 field size. Beam parameters are monitored using the record-and-verify (VARIS) system. **Results:** Reference dosimetry for the stationary and rotational

electron fields was performed to allow delivery of the prescription dose using the linac's transmission ionization chamber. Patients are treated on a rotating platform with a high dose rate rotational electron beam having a z_{max} at the skin surface, an R_{50} at 15 mm and a bremsstrahlung contamination of the order of 3%. The nominal dose rate to water at z_{max} (surface) for the rotational technique was determined to be 24.1 cGy/1000 MU, and beam delivery is monitored with a secondary Farmer-type ionization chamber located near the patient in the treatment field. **Conclusions:** Treatment times with the rotational total skin electron irradiation technique at an SSD of 378 cm for a daily dose of 2.0 Gy are of the order of 9.5 minutes and to date we have treated 15 patients with this technique.

SU-FF-T-388

Secondary Radiation Doses From CyberKnife SRS/RT

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Purpose: Because of extensive use of conventional x-rays in CyberKnife SRS/RT for treatment tracking and large number of monitor units (MU) in beam delivery, it is of great concerns of potential secondary radiation risks for patients with benign lesions. This study intend to determine the total secondary radiation dose and its components from both Linac and conventional x-rays, to estimate the risks, and to assist to better manage frequency of x-rays acquisition for treatment tracking and better guide through the treatment planning. Comparison with other modalities will also be discussed.
Method and Materials: A human phantom was constructed from the Accuray head phantom adjacent to a thoracic and pelvic body section from a commercial humanoid phantom. Measurements were taken at the surface and depth for both high-energy photons and conventional x-rays, respectively. Thermoluminescent dosimeter (TLD) chips were placed at 0, 10, 20 and 30cm from the pseudo isocenter. At depth, TLD chips were covered with bolus material for backscatter and/or dose buildup.
Results: The secondary radiation dose from conventional x-rays was about 0.1cGy per exposure inside the radiation field and fell off rapidly outside. The secondary dose from the high-energy photons was approximately 0.6cGy per 100MU at the distance 10cm from the pseudo-isocenter and fell off gradually. On average, the total secondary dose to a patient under CK SRS/RT would be 84, 42 and 40cGy at 10, 20 and 30cm away from the pseudo-isocenter, respectively. **Conclusion:** The secondary radiation dose to a patient under CK SRS/RT could be significant and high as compared to other similar modalities. During patient treatment, the frequency of x-rays acquisition should be carefully evaluated between the clinical necessity and potential radiation risks. This is also true in the process of treatment plan development during which the number of fractions and MUs would be determined.

SU-FF-T-389

Sensitivity of Document Scanners Used for Radiochromic Film Dosimetry

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Purpose: The use of color CCD-based document scanners, having an ability to perform scans in the transmission mode, has been suggested as an inexpensive option in the process of radiochromic film dosimetry. These scanners allow acquisition of transmission scans in up to a 48-bit red-green-blue (RGB) mode. Since the absorption spectrum of the radiochromic film exhibits a maximum in the red region of the visible spectrum, extraction of the red channel from the RGB image improves document scanner sensitivity when used in combination with radiochromic films. However; transmission scanners use a linear CCD array that suffers from a difference in response along the array. In this work, we present our measurements of the spatial response of an AGFA Arcus II document scanner used for radiochromic film dosimetry.
Method and Materials: To create various pixel value levels, we employed 5 neutral density filters and their combinations. The profiles were fitted with the sixth order polynomial and consequently used for image correction. The sensitivity curves have been created by normalizing their values to the central profile value.
Results: In the regions close to scanner bed edges, the non-uniformity of the raw pixel data depends on the pixel level detected by the CCD array and can be as large as 15%. Over the 80% of the scanning region, the uniformity is of the order of 2% after corrections are applied. However in areas close to the left and right edges of the scan deviations can reach 5% even after the correction. **Conclusions:** We have demonstrated that in transmission scanners, using linear CCD array detectors, a considerable change in sensitivity may occur along the detector array direction. If not properly corrected for, this spatial sensitivity may obscure a 2D accuracy of the radiochromic film dosimetry. **Conflict of interests:** Research is sponsored by ISP.

SU-FF-T-390

Setting Apart the Intensity Delivered to Moving Target, and Intensity Delivered to Moving Organ at Risk, in DMLC IG IMRT

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Purpose: To utilize tissue motion in order to benefit radiation therapy delivery. The approach makes possible to deliver the required by plan intensity to the target while sparing sensitive organs beyond what is attainable during delivery to static geometry of the patient body. **Method and Materials:** Few parameters can be identified which control the delivery of the intensity maps during DMLC IMRT that do not need to be unambiguously specified in order to paint a given, treatment plan derived, intensity over the target. In particular, the initial moment of DMLC delivery, speeds of the leading leaves of MLC assembly and the intensity rate of the beam can all be varied in some interdependent manner to minimize intensity to organs at risk without compromising the delivery of a given intensity map over the moving target. Formulas that define algorithms achieving these goals are presented. Special attention is given to simplified methods of multi-parameter optimizations for which subsequent parameters are treated independently. **Results:** Two examples of optimal sparing of organs at risk are provided for DMLC IGIMRT. In the first case the moment of initiation of radiation delivery as well as the speed of leading leaf is appropriately regulated with the aim of minimizing the cumulative dose delivered to the sensitive organ that performs periodic movement with respect to target. The second example minimizes the delivery to sensitive organ for identically moving target and organ at risk in the case when variation of the beam intensity rate is permitted during exposure. **Conclusion:** The method of DMLC IGIMRT allows improving the quality of radiation therapy when patient organs are moving at delivery. The required ingredients are: the a priori information about the motion of the target and organs at risk and the algorithm for the optimization of leaf trajectories for moving targets.

SU-FF-T-391

Simplified Monte Carlo Simulation for Absolute Dose Distribution of IMRT

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Purpose: A simple method was proposed to incorporate heterogeneous fluence distribution due to time-dependent leaf motion of IMRT delivery into Monte Carlo based static dose calculation to predict the dose distribution inside a patient and the transmission dose distribution at the EPID. **Method and Materials:** Weighting factors stored in an efficiency map was incorporated into an open photon field of the Monte Carlo simulation (BEAMnrc, 2005) to mimic the heterogeneous fluence distribution of an IMRT field. The efficiency map was obtained by dividing the measured in-air IMRT absolute dose distribution to that of the same open field using an aS500 EPID (Varian, Palo Alto, CA) which was carefully calibrated for absolute dose measurement. The EPID was setup at 140 cm SDD and 3.84 mm polystyrene phantom was used for the 6 MV photon beam to ensure full electronic buildup. Absolute dose calibration of Monte Carlo simulation was performed under a standard setup where absolute dose at a reference point was verified by ion chamber measurement. Transmission dose comparison at the EPID for two dynamic wedge fields and two IMRT fields as well as absolute dose distributions at the midplane (SAD=100cm) of a 24.8 cm polystyrene phantom among film dosimetry, EPID measurement and Monte Carlo simulation will be presented. **Results:** Max discrepancy of 3.3% was observed along the central axis for F1 IMRT field. In addition, penumbra along the field edge

of the Monte Carlo simulation appeared to be 1-3 mm wider than EPID and film dosimetry.**Conclusion:** A simplified method to incoporate heterogeneous fluence distribution of IMRT fields into static Monte Carlo simulation for absolute dose verification was proven feasible**.** The system can also serve as an independent absolute dose check system to commercial TPS calculation.

SU-FF-T-392

Simulating Absorbed Dose: Finite Element Modeling of a Stirred Water Calorimeter

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Purpose: To conduct detailed, finite-element studies of heat transfer mechanisms – in particular, heat conduction and forced convection due to stirring – in a room-temperature water calorimeter intended as a new primary standard for high-energy photon dosimetry. **Method and Materials:** The direct realization of absorbed dose is achieved by measurement of water temperature change of order 0.24 mK per Gy of radiation, posing experimental difficulties due to thermal and electrical noise**.** Prolonged irradiations can improve the signal-to-noise ratio, but the heat-transfer processes inherent to the calorimeter design can cause systematic errors in the results**.** We model the calorimeter components and the experimental conditions, and compare the simulation with data obtained experimentally**. Results:** We find that the simulated temperature history wave form agrees with experimental data if we include the forced convection treatment of the water external to the detection vessel**.** This is done by artificially raising the thermal conductivity of the water in the stirred region, simulating the actual magnetic stirrer deployed in the phantom**.** We also investigate artificially constructed scenarios that are difficult to achieve experimentally but offer closed-form solutions**.** We decompose both the spatial and temporal components and find that the simulated results indeed agree with the analytical calculation**.** We proceed to add up all the components such that they represent the results under realistic conditions**. Conclusions:** Finite-element modeling of a water calorimeter provides insights into the effects of heat transfer on the dose determination**.** The systematic response observed experimentally over a large time scale can be reproduced in the model**.** When broken up into components, the simulated response can be calculated analytically.

SU-FF-T-393

Source Measurement for Electron Monte Carlo Calculations

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Purpose: Monte Carlo calculations can reproduce most measured data for electron beams with very good accuracy**.** It should be possible, and arguably desirable, to be able to accurately reproduce all measured data with only knowledge of the linear accelerator geometry and the initial electron source; however, information regarding the latter is not as readily available**.** The purpose of this study is to study the properties of the electron beam close to the electron source. **Method and Materials:** Radiochromic film was inserted into a film holder consisting of two thin pieces of polystyrene, and attached to the distal side of the linear accelerator scattering foil assembly**.** For each electron energy, films were exposed to 50 and 100 MU**.** The films were scanned with a resolution of 89 microns, and images were converted to dose using film strips irradiated to known doses**.** For Monte Carlo calculations of the same geometry, the initial source was assumed to be Gaussian with a FWHM of 1.5 mm , and a phase space was collected between the polystyrene slabs**.** It was assumed that electron fluence was proportional to the film dose. **Results:** Agreement between measurement and calculation was generally very good, but better for higher energies**.** Varying the initial electron source in the Monte Carlo calculations showed that these profiles are relatively insensitive to the initial source size; profiles are dominated by scattering in the foil assembly. **Conclusion:** Because of the insensitivity of the profiles to exact details of the initial electron source, it may not be possible for these measurements to resolve the details of the initial source parameters**.** The results may have also been affected by the assumption that the electron fluence was proportional to film dose; therefore further calculations of the dose to the film (rather than fluence) need to be done.

SU-FF-T-394

Start-Up Characteristics of Elekta SLi-Linacs: Minimum Number of MU Required for IMRT

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Purpose: On Elekta SLi-linacs steering of flatness and symmetry starts after a user-definable delay of 0.5 to 1 s after beam-on, which equals 5 to 10 MU at 600 MU/min**.** The impact of start-up characteristics of Elekta SLi linacs on dose delivery with small segments during IMRT was investigated and the minimum number of monitor units needed per segment was quantified**. Method and Materials:** Linearity of the ionisation monitor was quantified by taking ionisation chamber readings for 10x10 cm^2 6MV and 10 MV photon beams over the range 1-200 MU**.** By using the Wellhöfer Beam Imaging System (BIS) dosimetric images of 820x820 pixels of the beam were acquired during the first 10 monitor units for 5 gantry angles (-180°, -90°, 0°, 90°, 180°)**.** Every 120ms images were taken of a 40x40 cm^2 field**.** All data are compared to the reference value after delivery of 10 MU, which is regarded to be the steady-state value**. Results:** Deviations in ionisation monitor readings were less than 0.5% for segments larger than 2 MU**.** For segments of 1MU readings were 1.5% less than expected**.** Values for symmetry and flatness of the beams were very large during the first MU but decreased within 2MU to twice the steady-state value at 10 MU**.** The integrated symmetry (defined as the symmetry of the integrated dose distribution) and integrated flatness decreased within 4MU to twice the steady-state value**.** Neither gantry angle nor energy had influence on these results**. Conclusion:** During IMRT segments of 4MU can be safely used for all gantry angles**.** Errors in dose are smaller than 1% and errors in symmetry and flatness are less than twice that of 10 MU segments.

SU-FF-T-395

Stereotactic Body Frame Apparatus

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Purpose: To improve immobilization and setup accuracy of patients undergoing extracranial radiosurgery (SBRT therapy)**.** Make possible SBRT treatments of oversized patients**. Method and Materials:** Advantages of frame based extracranial therapy are**:** (i) Reduction of the imprecision of positioning**.** (ii) Reduction of the geometrical treatment error in case frameless delivery tools malfunction**.** (iii) Efficient and reliable method of abdomen pressure for decreasing tissue motion effects**.** (iv) Comfort positioning that diminishes body movements caused by fatigue or pain manifest for an extended period of treatment**.** To utilize advantages of frame based approach to extracranial radiotherapy, and to also address some of the shortcomings of the existing immobilization devices, the new stereotactic body frame (SBF) has been constructed**.** The frame has been designed to be light, strong and rigid**.** The frame allows minimizing the disturbance of the penetrating radiation and facilitates its easy handling by therapists/physicists/physicians**.** The frame displays necessary rigidity to minimize errors associated with potential deformation**.** For these reasons the frame, as well as all accessories, have been all built from carbon fiber**.** The system is additionally equipped with the multimodal marker sources allowing synchronizing images of frame and patient body from a variety of imaging platforms**.** In summary, the new SBF frame allows dealing effectively with**:** (i) patient size limitations, (ii) abdominal pressure adjustments and pressure monitoring, (iii) stability and positioning accuracy of the measuring arc, (iv) fixation mechanism connecting frame to the couch (to utilize automatic couch motion capability), (v) facilitating extended distance SAD treatments**.** **Results:** The device satisfying considerations discussed above have been constructed**.** The device's parameters and accessories have been evaluated and its clinical applications defined and verified**. Conclusion:** The new carbon fiber immobilization frame for SBRT treatments is ready for clinical evaluation**.** **Conflict of Interest:** Research supported by a grant from Varian Medical Systems

SU-FF-T-396

Stereotactic Peripherial Brachytherapy and Image Guidance for the Breast

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Purpose: Breast brachytherapy may be applied peripherally without piercing the skin as currently performed with interstitial and MammoSite applications. By virtue of being a protruding and deformable organ, the breast lends itself to peripheral brachytherapy by non-invasive applicators. A delivery system was made (Advanced Radiation Therapy, Billerica, MA) to implement this developmental treatment modality using real-time mammographic image guidance for stereotactic applicator positioning and CTV localization. In this design, therapeutic dose to the lumpectomy cavity is delivered by externally placing opposing plaque-like applicators at multiple orientations to provide conformity while not exceeding the skin toxicity threshold. An initial assessment of this system was performed to determine clinical feasibility. **Materials & Methods:** The applicator geometry comprises two curved plates which slightly compress the breast to minimize slab thickness irradiated by the parallel-opposed plaque. Within the applicator are a series of parallel catheters spaced 1 cm apart. For a thickness of 6 cm, the breast geometry and applicators were simulated using analytical (Pinnacle^3 treatment planning system) and Monte Carlo (MCNP v5) techniques. A breast phantom was used for CT-based treatment planning; however, standard-of-care for brachytherapy dosimetry algorithms assume an infinite water phantom. CTV ellipsoids ranged from 2x4x4 cm^3 to 3x6x6 cm^3. Sources were positioned within the catheters to create a circular loading region (5 to 9 cm diam.) towards providing uniform CTV coverage. Dose homogeneity index (DHI) was determined for the skin. **Results & Discussion:** Average ratio of skin-to-tumor dose was < 0.9. Pinnacle and MCNP results indicated that DHI ~ unity for the CTVs studied. Dose to lungs, heart, and other critical organs was typically < 2%. These simulation results suggest that this technique may be an attractive APBI option. **Conflict of Interest Statement:** Advanced Radiation Therapy provided the applicator used in this study.

SU-FF-T-397

Stereotactic Radiotherapy: Varian 120-Leaf MLC Verses Radionics'' MMLC

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Purpose: With the continuing rapid development of technology, more options are becoming available for the clinician. However, this is bringing forth technical challenges to the Physicist, especially in the integration of these technologies. The most commonly used Varian linear accelerator that has the 120 leaf MLC attached to its head prohibits the use of an additional Radionics' MMLC. Hence the 120 leaf MLC was integrated into the Radionics' XKnifeRT system to be used in both cranial and extracranial applications. This presentation provides technical information and clinical experience using this combination. **Methods and Materials:** The stereotactic technology utilizes the Radionics' XKnifeRT system consisting of a) treatment planning software capable of both 3D conformal as well as step and shoot IMRT; b) stereotactic frames for cranial and extracranial applications. The Varian 120 leaf MLC with an inner leaf width of 5 mm was integrated into the XKnifeRT system so that either the 120MLC or the MMLC could be used clinically. The limitations in the use of the MMLC in this configuration include reduced clearance, especially for extracranial applications, and a reduced maximum field size of 9 x 11 cm. Thus far nearly 40 patients have been treated, mostly using the IMRT component, and include GTC/TLC for cranial sites, and, Head & Neck Localizer(HNL)/Body Localizer(BL) for extracranial sites. **Results:** A comparison of dose distributions/DVHs of the 120 MLC and the MMLC indicate only marginal improvement if the MMLC were to be used. Not only is the setup time at the linac reduced, the actual IMRT delivery is only a few seconds more than a corresponding dynamic delivery. A cranial and a C-spine application of the technology validates this integration. **Conclusions:** We continue to utilize the 120 leaf MLC successfully for all stereotactic applications with XKnifeRT.

SU-FF-T-398

Study of Inhomogeneous Dose Distribution in a Cell Box Due to the X-Ray Scattering Effect

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Purpose: The ratio of hypoxic to aerated doses needed to achieve the same biological effects, called the oxygen enhancement ratio (OER), is very important factor in radiotherapy since none produces such a dramatic effect and no other agent has such obvious practical implication. Although it is usually assumed that the dose distribution in a cell box is uniform, the absorbed dose to the tumor cells could be very different according to the locations of the cells within a cell box, which affects the cell survival curves. We have studied the inhomogeneous dose distribution in a cell box due to the scattering of x-rays with the cover and side-walls of cell box. **Method and Materials:** Three different sizes of cubical cell boxes, whose side lengths are 10, 15, 20 cm, were designed and irradiated by 6 and 15 MV x-rays using Varian 2100CD linear accelerator. **Results:** The differences of the absorbed doses at the center between 10x10x10 cm^3 box and 20x20x20 cm^3 box were less than 2 % for 6 MV and 15 MV x-ray irradiation, which indicates that the scattering effect depending on the size of cell box is not significant for the absolute absorbed dose at the center of box. However, the relative dose distribution within the cell box shows very different behavior revealing distinct heterogeneous dose distribution in a cell box. For example, the percentage showing more than 10 % dose difference within the cell box was ~ 40 % for 20x20x20 cm^3 box with 15 MV x-ray irradiation. **Conclusion:** While the dose inhomogeneity for 15 MV x-ray irradiation increases as the size of cell box increases, the dose inhomogeneity for 6 MV x-ray doesn't show any size dependency. Our experimental evidence suggests that the dose inhomogeneity within the cell box is not negligible.

SU-FF-T-399

Study the Difference Between IMRT and Forward Planning in Designing the Flash Required in Breast Treatemnet

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Purpose: Study the difference between IMRT and forward planning in designing the flash required in breast treatment **Method and Materials:** Using the Pinnacle^3 radiation treatment planning system to deliver a uniform dose to the Planning Target Volume (PTV) by using both forward planning techniques and inverse planning techniques (IMRT). The most important issue when it comes to IMRT breast treatment planning is to control the flash opening between the breast and the MLC in order to consider the breathing parameter. In forward planning 80% of the dose is delivered by open segmentation, and similarly, in IMRT the percentage of open segmentation can be controlled by drawing a flash target volume by extension of the PTV by 2.5 cm to 3.0 cm depending on the amount of flash desired. This flash target volume is included in the objective list of the IMRT parameters as "Uniform Dose" assigned to a minimum of 80% of the total prescribed dose and a minimal weight contribution such as 1E-15. In comparing IMRT and forward planning techniques, IMRT not only allows a percentage of flash similar to the forward plan but it also achieves a more uniform dose coverage of the breast both at superior and inferior borders with reduced dose to the surrounding structures such as heart and lung. **Results:** Using a flash target volume with minimal weighting as a objective parameters allows a higher percentage of each beam to be treated open in the modulated segmentation. **Conclusion:** For IMRT breast treatment planning, a flash target volume can be used as an objective parameter during optimization to help increase the percentage of segmentation to be treated as open.

SU-FF-T-400

Supine Craniospinal Irradiation Using Electronic Portal Imaging

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Purpose: The traditional prone patient position for craniospinal irradiation [CSI] is not suitable for paediatric patients requiring anaesthetics. A new supine CSI technique was developed to implement crucial features of the

prone technique—the ability to palpate the spine and pre-treatment verification of junctions. **Methods and Material:** Fourteen patients have been treated using a custom treatment board, which indexes to the CT and Varian Exact™ couch. Patient were immobilized with a thermoplastic head-and-shoulder mask secured to the board. Three-dimensional CT based plans were developed with the collimator of lateral opposed cranial fields rotated to match the beam divergence of the posterior spine field. The fields junction along a common line running through the mid-sagittal plane.
The junction was confirmed using a 2 mm radio-opaque marker placed daily on the anterior surface of patient's mask at the intersection of inferior border of cranial fields. Pre-treatment electronic portal images of the lateral cranial and posterior spinal field borders were captured and assessed to confirm the position of the field junction, with discrepancies greater than 2.0mm corrected prior to treatment delivery. **Results:** This new supine CSI technique has improved patient comfort, treatment set-up reproducibility and stability. It mirrors the prone technique in matching field junctions and maintaining the ability to palpate the spine. Standard EPI measuring tools facilitate the assessment of marker position relative to the field edge and patient anatomy.**Conclusion:** Supine CSI has increased patient safety through improved airway access in the event of respiratory distress. Supine positioning facilitates alternative distraction devices, such as video entertainment, reducing the need for anaesthetics in the paediatric population. The couch indexing system has allowed a more accurate monitoring of treatment set-up, as demonstrated by a decrease in post-planning shielding modifications. The supine technique is preferred for patient comfort, precise junction match, and demonstrated reproducibility.

SU-FF-T-401

Surface Dose Measurement in 6 MeV X-Ray Beam Using Radiographic Film and TLD

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Purpose: The purpose of this study was to estimate and compare the surface dose in 6 MV x-ray beam using TLDs, radiographic film and parallel plate ionization chamber. **Method and Materials:** The surface dose measurements were performed in a 6 MV x-ray beam of a medical accelerator (Varian 2100 C/D) with X-Omat V (Ready Pack) radiographic film, LiF thermoluminescence dosimeters (TLD-100) and parallel plate ionization chamber (PTW) for 10x10 cm field size. The film was placed perpendicular to the beam axis at the surface and at different depths of a solid water phantom, placed 100 cm from the source (SSD=100). The film was calibrated to convert optical density to dose. For TLD measurements, five TLDs were inserted in the center of 2 mm thick Perspex plate and placed at different depths in a solid water phantom. Each TLD was individually calibrated. A Parallel Plate Chamber was placed in a solid water phantom at different depths and the doses were extrapolated to estimate the surface dose. **Results:** The estimated surface dose with radiographic film was found 17.4% ± 3% and with the TLD technique was found 23% ± 3% relative to maximum dose. The corresponding parallel plate ionization chamber extrapolated dose was 17.8 % ± 2% relative to maximum dose. **Conclusion:** Radiographic film measurement of surface dose showed good agreement with the parallel plat ionization chamber in this study. With TLD-100, the measured surface dose was higher than chamber and film measurements due to the positioning of the TLD in the phantom and the inaccuracy of the effective point of measurement.

SU-FF-T-402

Synchronized Dynamic Dose Reconstruction

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Purpose: To present a dose accumulation method that explicitly incorporates real-time target volume motion, and real-time machine configuration, MLC motion and fluence state. **Method and Materials:** Effects of inter- and intra-fraction motion on dose distributions delivered to a target volume are typically estimated by statistical methods that rely on idealized assumptions such as constant random and systematic errors, and constant offsets, periods and amplitudes of motion over the entire course of therapy. In addition, implementation and delivery related issues such as leaf sequencing limitations, spatial interplay between MLC leaf and target volume motion, and temporal interplay of the fluence state in IMRT, are assumed to average out during treatment. To include these effects, a dose accumulation technique is proposed which explicitly incorporates real-time target volume motion data, and real-time treatment machine data. Several technologies are becoming available to continuously monitor (10-30 Hz) the patient position, organs-at-risk, and the target volume during therapy. Likewise, real-time (20 Hz) machine configuration, leaf position and fluence state data, is currently available in the Varian DynaLog files. These datasets are synchronized at the beginning of each beam; and the Monte Carlo method, which inherently accounts for time dependence, was used for dose calculations. **Results:** By synchronizing target volume position, machine configuration, leaf positions and fluence state, with sub-second resolution, the dose delivered by each beam, may be accumulated. Such accumulated dose distributions reflect the interplay between target volume motion, MLC leaf motion and other machine-related delivery effects based on real-time, patient specific, measured data. The delivered dose distribution to date may then be compared to the planned dose distribution to provide input for dynamic refinement of treatment planning and delivery. **Conclusion:** Delivered target volume dose may be reconstructed using real-time motion and machine data, and serve as a basis for dynamic refinement of treatments.

SU-FF-T-403

Target Failure and Beam-On Load in Helical Tomotherapy

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Purpose: To predict target failure for a Helical Tomotherapy unit based on cumulative beam-on time. **Materials and Methods:** Helical Tomotherapy is a novel external beam clinical technology and as such it presents new quality assurance challenges. Our unit started treating patients in April 2004. By February 2006, the x-ray target had been changed three times (03/05, 09/05 and 01/06). On visual inspection, a damaged disk-target shows an annulus of severe wear. In one case, the annulus cut through the entire thickness so that the target was split into two parts. Another target had pieces of the outer rim flaked off. Near the failure of a target, machine output changes significantly (>±3%), which requires additional output checks and tuning, and it can also result in treatment interruptions. Although the output seems to decrease most of the time nearing target failure, increases have also occurred. Output variations can be explained by the nature of the target disintegration and its impact on the water-driven target rotation and cooling. We hypothesized that target failure frequency is related to cumulative beam-on time. Since a target replacement almost always entails clinical downtime, such a relation would be useful in predicting when a target change should be scheduled. **Results:** We collected beam-on data—including daily and patient specific QA procedures but excluding MVCT beam-on and engineering time—for periods between target changes. The first, second and third periods of 12, 5.75 and 3.75 months had total beam-on times of 369, 212 and 136 hours, respectively. The average daily times for the same periods were 1.4, 1.68 and 1.65 hours. **Conclusion:** These data are not yet conclusive but do suggest that lower average daily load impacts on target life stronger than cumulative load. An extended analysis of target wear and beam-on statistics, including MVCT times, will be presented.

SU-FF-T-404

Techniques Developed to Improve the Quality of Total Body Irradiation

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Techniques and Procedures Developed to Improve the Quality of Total Body Irradiation

Purpose: Half-standing position has been used in our clinic for Total Body Irradiation (TBI) treatment for better patient comfort and dose uniformity. Several compensation techniques and diodes calibration procedures were developed to improve the quality of total body irradiation (TBI) treatment. **Methods and Materials:** A frame was designed to stand on the linac couch and to hold the Cerrobend lung blocks. The blocks were mounted on a polystyrene board, which was screwed on the frame. The position of the blocks could be adjusted with the vertical movement and certain rotation of the board. It could then be fine tuned by moving the couch vertically and laterally. The source to patient's mid-plane distance is 400 cm, and the block to patient's mid-plane distance is 200 cm. An house-made rice bag

was used to compensate the thickness of the patient's neck, and the linac jaws were partially closed during the treatment to compensate the dose to patient's lower legs. The dose distribution was monitored by in-vivo diodes, which were calibrated at Dmax with treatment distance. **Result:** Since the blocks were halfway in-between the source and the patient's mid-plane, they were not heavy and their penumbra was small. It was easy for therapists to positioning the blocks. The thickness of the neck was well compensated by the rice bag, the deviation of the dose measured at the neck to the prescription was reduced from 8-9% to 2-3%. The Dmax dose measured at the prescription site was in good agreement with the calculated Dmax dose. The differences were usually within 5%. No corrections of the diode's readings were necessary for the variation of patients' separations. **Conclution:** The TBI technique provides a simple and efficient method to deliver high quality treatments.

SU-FF-T-405

Temporal Correlation in Monte Carlo Sampling to Evaluate Interplay Between Tumor and MLC Motion in IMRT

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In radiation therapy, tumor motion due to normal breathing displacements can smear out dose distributions. An additional problem in MLC-based IMRT is that the phase relationship between the patient's breathing and each MLC segment differs between fractions. For courses lasting only a few fractions, it is necessary to also evaluate the MLC-tumor interplay effects. However, calculating such effects requires precise values of quantities, such as, the starting breathing phase (τ_0), machine's dose rate (DR), interbeam delay (τ_g) and intersegment delay (τ_s). Though it may be infeasible to perform time-dependent calculations for specific deliveries, we can estimate the interplay effect by assuming typical timings involved. In this work, we extend the Monte Carlo Superposition dose engine to analyze interplay effects. The algorithm starts by randomly sampling a beam and field segment. For the segment sampled, the time elapsed until that point is calculated by using typical values of DR, τ_g, and τ_s. This time is then correlated with the tumor trajectory, and the isocenter is shifted accordingly. Photons are them sampled from the head and propagated through the collimator and the phantom. Energy is deposited by kernels issued from the photon interaction sites. Different fractions were simulated by using different τ_0. We analyzed the interplay effect by comparing correlated simulations with uncorrelated simulations (infinite fraction average). It was found that the interplay effect varies strongly with the dose rate, number of fractions, type of leaf sequencing (close-in vs. sliding window) and the direction of motion with respect to MLC's. More complex dependencies occur with MU efficiency and segment numbers. The correlated time Monte Carlo sampling method provides a way to ensure that the dose received by the patient will not deviate significantly from the more predictable ensemble average for the chosen treatment dose rate and the number of fractions.

SU-FF-T-406

Testing of ATC Method 2 for Supporting QA of Cooperative Group Advanced Technology Clinical Trials Requiring Digital Data Submission

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Purpose: To test the readiness of a system of software ("ATC Method 2-v.2.3") developed by the Resource Center for Emerging Technologies (RCET) for supporting QA of cooperative group clinical trials within the Advanced Technology QA Consortium (ATC). **Method and Materials:** ATC Method 2-v.2.3 includes WebSys client and server for secure data upload/download/archiving of volumetric imaging and radiotherapy treatment planning data, a web-based Rapid Image Viewer (RIV) tool, and web-based tools for server administration. The software was implemented on a test server at the Image-guided Therapy QA Center (ITC), and underwent rigorous testing by ITC personnel. Tests conducted included examination of user interface behavior, as well as systematic comparison of submitted/retrieved copies of 16 representative test data sets (in DICOM and RTOG Data Exchange format) from nine different treatment planning system vendors. **Results:** Evaluation tests of version 2.3 of the ATC Method 2 software identified improvements in the usability of software over the previous version, and provided general suggestions for further improvement. These tests also identified specific input that led to failure of the WebSys client, usability issues in the RIV tool, database changes needed to support case identifiers in ATC trails, and corrections needed in handling certain DICOM objects. These test results have contributed to improvements in version 2.4 of this software in preparation for its use to support clinical trials. Version 2.4 is expected to be ready for testing beginning March 2006. The National Cancer Institute of Canada (NCIC) Clinical Trials Group (CTG) will participate in the new round of testing. **Conclusion:** Since this software is intended to play a major role in QA of data submitted for future ATC-supported clinical trials, rigorous testing is essential to its ongoing development. Future testing is expected to benefit from collaborative efforts of NCIC CTG.

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SU-FF-T-407

Testing the Accuracy and Usefulness of the Portal Vision Dosimetry System for Large-Volume and Complex-Geometry IMRT

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Purpose: To test a commercial EPID dosimetry system for the accuracy and usefulness for head&neck, whole-pelvis, mesothelioma IMRT QA. **Materials and Methods:** Portal Vision (PV) dosimetry system was configured and experimentally used as intended by the manufacturer (Varian) for 6MV 2100Ex. Additional data analysis software was developed. Collimator angle=90deg and the smallest possible SDD=105cm and were selected to maximize the functional area of the EPID. EPID responses were calculated by Eclipse and compared to the experimentally determined responses in two ways: by comparing individual images and 3D-response reconstructions for cumulative plans (home-built software). To account for the PV arm sag during gantry rotation, and the need to shift the detector, raw PV images were automatically magnified and registered with calculated images. 3D-response reconstructions for the measured and calculated images were performed by: backprojecting the images and applying attenuation and phantom scatter in a homogeneous virtual patient. Patient beam configuration and depths to isocenter were used. **Results:** PV dosimetry for large/complex targets is difficult and time-consuming due to practical limitations (detector size, arm sag, manual shifting). Experimental response images show strong tongue&groove effects and elevated values outside of the field edges compared to Eclipse. Response discrepancies inside treatment fields cause (±2-3%) discrepancies in cumulative plan. Discrepancies outside of field edges cause systematic shift up to (5-7%) in cumulative plan, because fluences are split into 2-3 narrower subfields in the delivery. The observed discrepancies are consistent with but stronger than ion chamber measurements in solid water. The reason may be the small 1cm-buildup and therefore larger PV sensitivity to MLC scatter and T&G. **Conclusions:** Neither MLC scatter nor T&G are modeled in Eclipse. Their contributions may be significant for large/complex IMRT due to the increased MLC blockage. PV dosimetry may capture these effects, but caution is indicated in interpretation.

SU-FF-T-408

TG21 In-Air Measurements of Elekta Gamma Knife Dose Volumes

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Purpose: To implement TG21 dosimetry protocols and in-air measurements to determine the dose rate of fields resulting from the 18mm and 14mm helmets of an Elekta Gamma Knife (GK) unit. Methods and Materials: An air ionization chamber with a collecting volume of 0.007cm^3 was used to make in-air measurements at the physical isocenter of a GK unit. The isocenter was determined and the chamber was positioned in air using a chamber holder and laser positioning system. The dose rate to water was determined using the TG21 formulism designed for use with Co-60 teletherapy machines. Only a measurement taken at the isocenter of the machine is required. Certain chamber-specific correction factors and a chamber calibration factor are also used. The clinical dose rate is determined by Elekta from measurements taken in an 8cm radius spherical

phantom. For comparison this clinical dose rate can be corrected out of phantom using tissue-air ratios. The experimentally determined dose rate is then compared with to the corrected clinical dose rate. **Results:** The dose rate for the 18mm and 14mm helmets determined using TG21 is within 1% of the Elekta-provided clinical dose rate after correction out of phantom. The dose rate was also experimentally determined for the 8mm and 4mm helmets. The experimental dose rate is low for these helmets due to the field fall off within the chamber volume. **Conclusion:** TG21 in-air measurements may be performed with the GK unit providing the field size is large enough to appear as a uniform field to the ionization chamber. These measurements allow GK dosimetry to be performed with an established dosimetry protocol and without complications arising from phantom material. This will allow further developments of in-air calibration methods appropriate for the 8mm and 4mm fields of GK units to be compared to a well established standard.

SU-FF-T-409

The Computational Environment for Radiotherapy Research: New Tools for Multi-Modality Imaging, Treatment Plan Comparisons, and Plan Evaluations

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Purpose: CERR (a Computational Environment for Radiotherapy Research) is an open-source Matlab-based set of tools for conducting radiotherapy research which has been available for several years. In order to make CERR as useful as possible to radiotherapy researchers, we have added multi-modality imaging support as we as new dosimetric and radiobiological plan review tools. **Method:** The existing DICOM Import tool box in CERR was upgraded with capability to import PET, MR and SPECT DICOM images. While MR and PET are single frame image sets, CERR seamlessly imports multiframe SPECT DICOM. Automated and interactive registration tools were developed. A new metric selection GUI provides user ability to select a variety of metrics and save a 'plan evaluation set' for later use. When adding an individual metric, the user can select applicable parameters as well as information about criteria, including passing and marginal values, and priority. The metrics can then be compared on a graphical display or a report can be generated which lists passed/marginal/failed for all criteria and displays a score for each dose distribution. Several new dose comparison tools have been added, including: (1) side-by-side dose comparison views, (2) dose subtraction views for up to three dose distributions compared to a reference distribution, and (3) a 3-D slicer view which paints differences on coordinate system or transparent anatomic structure surfaces. **Results:** CERR continues to undergo continuous development to provide a wide range of tools for image-guided research. The latest release can be downloaded from www.radium.wustl.edu/cerr. CERR can be used freely only for research work. **Conclusions:** New CERR tools can facilitate research in adaptive and 4-D treatment planning.

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SU-FF-T-410

The Credentialing Process for the NSABP B-39/RTOG 0413 Partial Breast Irradiation Trial

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Purpose: Develop a credentialing process for the NSABP B-39/RTOG 0413 Partial Breast Irradiation (PBI) trial. **Method:** NSABP B-39/RTOG 0413, a Phase III trial comparing whole breast irradiation versus PBI (3D conformal radiation therapy (3D-CRT), MammoSite® and multi–catheter brachytherapy). For each PBI technique, an institution, radiation oncologist and physicist team must be credentialed. The credentialing verifies that all personnel involved with treatment planning have read the protocol prior to enrolling patients to limit the number of deviations. Credentialing also allows feedback to the team prior to patient treatment to correct any mistakes. Each institution must complete online the knowledge assessment and facility questionnaires and download a PBI technique CT benchmark case. **Results:** Teams at 308 distinct institutions have submitted applications for credentialing for at least one PBI technique. 733 radiation oncologists applied for 3D-CRT credentialing, 490 radiation oncologists for MammoSite® and 151 radiation oncologists for multi-catheter. Of those applications, 79% became credentialed for 3D-CRT, 69% for MammoSite®, and 56% for multi-catheter. Reasons for which a radiation oncologist failed to become credentialed included; incomplete application, incorrect answers on knowledge assessment, treatment planning system could not submit data electronically, and the CT benchmark was not planned per protocol. The first patient enrolled by each institution received a rapid review prior to patient treatment. The next 4 cases received a timely review. These reviews included a dosimetric and clinical review. Currently, this protocol has accrued 880 patients, of which 328 treated with 3D-CRT, 82 treated with MammoSite, and 31 treated with multi-catheter brachytherapy. Of the 441 patients treated to date on the PBI arm there have been no dosimetric deviations. **Conclusion:** The PBI credentialing process has been successful in educating participating facilities and helping to minimize dosimetry errors.

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SU-FF-T-411

The Delivery of DMLC IMRT to Stationary and Moving Targets with Variable Intensity Rate Beams

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Purpose: Time dependent intensity rate delivery for DMLC IMRT therapy increases the efficiency of IMRT treatments for stationary and moving targets. **Method and Materials:** The method of time dependent intensity rate DMLC IMRT relies on algorithms relating leading and following leaf velocities over their subsequent positions over the target with the intensity rate (dose rate) of the linear accelerator. Allowing the choice of leading leaf velocity over subsequent points over the target and the choice of beam intensity rate parameters, provided special mutual relationships between these quantities are preserved, allows to deliver treatment plan derived intensity maps to targets while adjusting the amount of radiation to which organs at risk are exposed. This ability to chose, within limitations that assure delivery of given intensity profile over the target, the leading leaf speed and the beam intensity rate, creates a situation when optimized delivery, optimal in the sense of minimal dose being delivered to organs at risk, can be achieved. Considerable technical simplification of the described above optimized DMLC IMRT delivery problem may be implemented if adjustment of intensity rate is treated independently from other parameters and treated as straightforward scaling of the time axis. This approach separates two parameter (functional) optimization problem into two single parameter optimization problems. **Results:** Two simple examples of variable intensity rate DMLC IMRT delivery are calculated. One concentrates on optimization of the time of delivery in case of stationary target. The other one shows the optimization of the time of delivery for moving target. **Conclusion:** The method of time dependent intensity rate DMLC IMRT delivery shows considerable potential for improving the efficiency and the quality of IMRT treatments.

SU-FF-T-412

The Development of Multiple Heterogeneous Head and Neck Phantoms for Quality Assurance of Inhomogeneity Correction Algorithm in the Intensity Modulated Radiotherapy and Conformal Dynamic Arc Radiotherapy

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Purpose:To quantify the differences between heterogeneous dose estimates from the calculation algorithm of 3-D treatment planning systems and dosimetry measurements, radiation was delivered in accordance with IMRT and conformal dynamic arc radiotherapy (CDART) QC procedures using multiple heterogeneous head & neck phantoms. **Method and Materials:** The multiple inhomogeneous head and neck phantoms were constructed by various materials such as water equivalent homogeneous (acryl), air equivalent (cavity), bone equivalent (teflon) materials. The absolute and relative dosimetry were done using pinpoint ionization chamber, film and TLD (Harshaw 100). With custom-written software modules, the measured and calculated dose distributions were superimposed and compared.

Results: The point dose measured at the interface between water and air material region shows about 7 % mismatch with the treatment planning system in IMRT. This dose difference is even increased at the interface between bone and water material region reaches up to 18 % under-dose comparative to planned value. However, the point dose error at the interface between water and bone material region is relatively small showing about 3.2% over-dose. In CDART, the distribution verification result shows that there is a mismatch of about 1.5 % of whole points revealing more than 5% of the dose difference between measured values and planning value when the inhomoheneious phantoms are used. Our results suggest that the effectiveness of the imhomogeneity corrections used in IMRT and CDART planning should be evaluated in order to ensure meaningful quality assurance and delivery.**Conclusion:** The robustness of inhomogeneity correction used in IMRT and CDART treatment planning may be a significant factor in assuring predictable, accurate delivery of IMRT.

SU-FF-T-413

The Deviation of Leaf Position in DIMRT

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Purpose: To analysis the deviation of leaf position on fraction size and on dose rate in dynamic IMRT (DIMRT). **Methods and materials:** The shape of target, which is similar to 60^0 wedge profile, was drawn at 11.5cm depth in phantom on the Eclipse system. The field size is set as 11.3*16.0 cm^2 and energy used is 6 MV. The constraint of optimization of target is kept the same, using single portal, for different fraction sizes which varied from 500cGy/fx to 5cGy/fx. The treatment file is transferred to LINAC for beam-on at Varian 21EX. The MLC log file is analyzed using MLC dynalogfile viewer 6.2.0. We varied the dose rate during beam-on for the same treatment file to take the leaf deviation data. **Results:** Dose rate 300MU/min is using in clinical treatment. It is the least error for dynamic leaf for the biggest fraction size with single portal. The quantity, field width multiplied dose rate then divided by MU, is used to evaluate the average speed of dynamic leaf. The evaluated average speed is 89.2 (cm/min) and 121.1 (cm/min) for 10cGy/fx and 5cGy/fx respectively and the larger speed caused the large average deviation around 0.4mm and 0.6mm respectively. The maximum deviation is 1.0mm and has 37.7% in deviation histogram for the smallest fraction size, 5cGy/fx.
For the same fraction size, 5cGy/fx, the dose rate affected the leaf deviation too. A larger dose rate has larger average leaf speed and a large deviation too. Our data showed the average speed is 242.2 (cm/min) and the average deviation is 0.9mm for dose rate 600MU/min. With this dose rate, the maximum deviation is 2.5mm and has 14.3% in deviation histogram. **Conclusion:** The positions accuracy is better for lower dose rate even with a large dose fraction.

SU-FF-T-414

The Dose Area Product in Radiation Therapy- a New Concept for the Parameterisation of Small Fields

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Purpose: To establish a new parameterisation of small fields.
Material and Methods: The traditional parameterisation of a narrow photon field via the central axis dose and the relative transversal dose profile has met considerable methodical complications. These difficulties are to find a sufficiently small detector, to adjust the detector accurately on the axis of the narrow beam and to find a detector material not responding to lateral changes of the electron spectrum within the small field. These obstacles can be avoided by reconsidering the parameterisation of the narrow-field dose distribution. The new parameter recommended for characterising the absolute dose values in a plane perpendicular to the beam axis is the *dose-area product* DAP (the area integral of the dose in this plane). It can be measured with a flat ionisation chamber of large cross section of the sensitive volume. **Results and Conclusions:** The radial adjustment of the large area chamber is by no means critical. The dose-area product provides a simple normalisation of the relative transversal dose distribution which can be measured with radiochromic film. We have investigated the abilities of a large-area flat ionisation chamber of PTW Freiburg (PTW TM 34070-2,5) of 8,1 cm diameter and 2 mm thickness of the sensitive volume to measure the DAP of narrow photon beams with side lengths up to 5 cm. A modified output factor has been defined as the quotient of the DAP, measured at 5 cm phantom depth for SSD 100 cm distance of the phantom, and the monitor reading. Besides the useful feature of the DAP is its direct measurability during patient treatment by means of the DAVID chamber, an on-line monitor arranged in the accessory holder, so that non-negligible deviations of the actual from the chosen field size of narrow photon fields can be immediately detected.

SU-FF-T-415

The Effect of MLC Geometry On Monte Carlo Simulated Beam Output for IMRT

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Purpose: This work studies the effect of detailed multileaf collimator (MLC) geometry on beam output for small MLC segments in Monte Carlo dose calculation for IMRT planning and quality assurance. **Method and Materials:** An analytical examination of the geometrical structures between the linac extrafocal source and the isocenter plane was evaluated. The main source, a small extended source, can contribute almost the same to every point at the isocenter plane while the extrafocal source, at the level of the flattening filter, may be partially blocked by the MLC leaves. The Siemens MLC geometry, with 7.7cm thick leaves was used to investigate the blocking effect. The flattening filter is 18.3cm above the MLC and the isocenter is 64 cm away from the MLC. The Monte Carlo method is an accurate method to predict the deliver doses to the patient; however, the beam output variation due to the detailed MLC geometry may introduce uncertainties in the Monte Carlo dose calculation. **Results:** A 1x1 cm opening at the isocenter plane 2.5cm away from the central axis can project a 0.24x0.33 cm area on the secondary source plane. While in Monte Carlo calculations, a 0.33x0.33 cm area is used. In order to precisely predict the effect of MLC blockage on beam output, a multiple Gaussian source at the secondary source plane (S. Jiang et al, Med. Phys. 28, 55, 2001) was used in this work. The integral scatter contribution from the real case differs from that used in Monte Carlo calculation by about 1.0%. This means the Monte Carlo method will predict a 1.0 % higher accumulated dose due to the overestimation of the exstrafocal source. **Conclusion:** Small (1-2%) uncertainties on the IMRT dose distribution calculated by the Monto Carlo method are predicted using reconstructed intensity maps rather than using detailed MLC geometry.

SU-FF-T-416

The Effect of Skin Flash On Skin Dose for Breast IMRT Treatment

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Purpose: Treatments using tangential IMRT fields for Breast treatment are prone to fluctuation in the body outline area. Deviations may arise from inaccuracies in patient positioning, patient movement, or respiratory motion. The skin flash tool from Eclipse, which visualizes the fluence of the selected field in the BEV, allows the planner to graphically extend the fluence outside the body surface with a paintbrush. The painted extension is then filled with transmission values. The purpose of this work is to investigate the effect of skin flash tool on skin dose for breast IMRT treatment. **Method and Materials:** A breast phantom filled with tissue equivalent material was constructed to investigate the skin dose. The IMRT tangent fields, which reproduces the two fields traditional setup for breast irradiation, was used to generate IMRT plan based on the CT images. The skin flash tool was used to extend fluence 2 cm outside the breast skin to accommodate the respiratory motion. The skin flash was then filled with different transmission values ranging from 0 to 1 to generate different plans. Skin dose was then measured on these plans using diode. The respiratory-gated treatment was also measured. **Results:** Compare to the skin dose through conventional parallel opposing tangential beams with wedges, the variation of skin dose is +-15% with transmission values ranging from 0-1. The transmission value of 0.5-0.6 produced the plan with similar skin dose to the conventional plan. If measurement was done with the respiratory motion, the skin dose variation could be +-25%. However this variation could be reduced to +-20% if gated treatment was used. **Conclusions:** The skin flash transmission factor should be kept at

0.5-0.6 in order to keep the skin dose similar to those from the conventional plan. Breast gating treatment minimizes the skin dose variation.

SU-FF-T-417

The Effect of Target Volume Depth On Surface Dose for Inverse Planned IMRT Treatments of Head and Neck Cancers

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Introduction: This work evaluates the surface dose as a function of PTV proximity to the surface for inverse planned head-and-neck IMRT patients and compares the results to measurements performed for a conventional treatment technique. Methods and Materials: An anthropomorphic phantom was CT scanned in the supine treatment position with thermoplastic mask immobilization covering the entire head-and-neck excluding the supra-clavicular region. A CTV including the cervical, low neck, and supra-clavicular lymph nodes, as well a 5 mm margin was outlined. Inverse IMRT plans were generated using a 7 field coplanar technique with 6 MV photons. Plans were created for PTVs defined at 0, 5, and, 10 mm depth from the phantom surface (PTV_{skin}, PTV_5, PTV_{10}). The treatments were delivered using a dynamic multileaf collimator sliding window technique. Measurements at up to 8 locations on the surface of the phantom and at 2 locations near the center of the PTVs were performed using TLD and MOSFET dosimeters. Results were compared to measurements performed for a conventional 3-field geometry (opposed laterals and anterior supra-clavicular field planned to cover the PTV_{skin}). **Results: and Discussion:** The average surface dose for the IMRT plans in the neck region was measured to be 59%, 78%, and 92% of the prescription dose for the PTV_{10}, PTV_5, and PTV_{skin} plans respectively, and likewise, 53%, 55%, and 73%, respectively in the supra-clavicular region. Average surface doses from the conventional field arrangement were measured to be 100% and 36% of the prescription dose for the neck and supra-clavicular region respectively. **Conclusion:** For the IMRT plans the surface dose increased as a function of the PTV proximity to the surface. For an equivalent prescription dose, the conventional 3-field technique yielded a higher average skin dose in the neck region and lower dose in the supra-clavicular region in comparison with the IMRT plans.

SU-FF-T-418

The Effect of Total MU, Number of Segments, and Field Size On IMRT Point Dose QA Results

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Purpose: To investigate the relationship between Corvus IMRT treatment plan parameters (total MU, number of segments, and average field size) and point dose QA results (ion chamber measurements and RadCalc independent MU calculation software). **Method and Materials:**
The Corvus treatment planing system (TPS) employs a "calibration factor" in its dose calculations. We determined this factor using a set of test plans with an average of 555 MU, 220 segments, and 7.3x7.3cm2 equivalent square field size. The TPS was then used to calculate 95 patient plans. Hybrid plans were created by transferring patient plans to a 30x30x18 cm3 solid phantom. A 0.3cc ion chamber and Kodak EDR2 film were placed inside the phantom. The treatment fields were delivered on a Varian 21EX via the QA Mode of Impac Multi-Access R&V system. For each plan, dose to the isocenter was calculated with RadCalc and compared to the plan's prediction. Ion chamber and RadCalc percent error values versus total MU, number of segments, and field size are plotted and analyzed with the Pearson's product moment correlation coefficient. **Results:** The data indicate that for this equipment configuration, both ion chamber measurement and independent calculation percent error results are directly proportional to total MU, number of segments, and average field size. In general, RadCalc predicts a smaller percent error than ion chamber measurements for all three variables. For ion chamber measurement, field size produces the strongest positive correlation with percent error and MU the weakest. For RadCalc percent error, number of segments produces the strongest correlation and field size the weakest. **Conclusion:** For the Corvus TPS, the measured dose percent error increases as the total MU, number of segments, and field size increases beyond the average value used to determine the calibration factor. RadCalc independent MU calculation software predicts the same trend.

SU-FF-T-419

The Impact of Gating On the Reduction of Heart Doses for Left Sided Breast Cancer Irradiation

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Purpose: Because there are indications for an increased risk of cardiovascular diseases after radiotherapy of the left chest wall the dose to the heart should be reduced as far as possible. With respiratory gating technique irradiation can be restricted only to the inspiratory plateau phase. We investigated in all patients with left sided breast cancer dose reduction to the heart when treated only in the inspiration phase compared with not gated treatments. **Materials and Methods:** Between Sept 2004 and Feb 2006 107 patients with left sided breast cancer were treated with respiratory gating technique based on a retrospective 4D CT scan. We performed for all of these patients a normal and a respiratory gated planning CT. Planning was done with the same treatment parameters in both CT. DVH for the entire heart and the anterior left ventricle wall were calculated. All patients were treated with 2 Gy single dose to a total dose of 50 Gy to the entire left breast/chest wall. 68 patients received an additional boost of 10 Gy. **Results:** The mean dose to the entire heart was 0.7 Gy without and 0.6 Gy with respiratory gating (p=0.04) whereas the mean maximal dose was 40.2 Gy without and 11.7 Gy with respiratory gating (p=0.0003). The anterior heart wall receives 2.4 Gy without and 1.2 Gy with respiratory gating (p=0.0001) with a mean maximal dose of 39.6 Gy without and 10.1 Gy with respiratory gating (p=0.0004). **Conclusion:** 4D analysis has shown that the distance between the PTV and the heart is influenced by two separate parameters. Besides the movements of the chest wall the heart is pushed into the irradiated volume also by the diaphragm. Respiratory gating and irradiation only in the inspiratory phase significantly reduces radiation doses to the heart and especially to the anterior heart wall.

SU-FF-T-420

The Impact of Random and Systematic Errors of MLC Leaves On Head-And-Neck IMRT Plans

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Purpose: To investigate dosimetric effect of the random and systematic errors of MLC leaf positions on the IMRT plans for patients with head and neck cancer. **Method and Materials:** For six clinical IMRT plans, random errors (from -2 to 2 mm) and systematic errors (±0.5 mm and ±1 mm) MLC positioning errors were introduced into the each segment for these plans, simulating the mechanical uncertainties and potential mis-calibration of the MLC. The altered MLC segments for each plan were imported to a commercial treatment planning system to evaluate dosimetric changes of the plan. The altered plans were compared to the original plans, based on DVHs and defined endpoint doses. **Results:** With the up-to-2 mm random errors in MLC positions, the dose changes to the 95% of the tumor volumes were (-1.247± 1.153)%. For serial structures, the dose changes to the 0.1 cc of the brainstem and spinal cord were (0.230±0.794)% and (–0.340±1.254)%, respectively. The dose changes to the 50% of the parotids varied from patient to patient, from 0.536% to 11.333%, (1.641±4.274)% and (4.910±5.322)% overall. With systematic errors in MLC positions up to 1 mm, the dose changes to the 95% of the tumor volumes were (-0.078±1.048)%. The dose changes to the 0.1 cc of the brainstem and spinal cord for all patients except one were (0.591±1.058)%. The dose changes to the 50% of the parotids overall were (7.782±3.111)%, beyond 5% limit. **Conclusion:** The dosimetric changes introduced by the random errors for each leaf within 2mm were not significant compared to the original plans. The systematic error up to 1mm for each leaf did not significantly changed the target dose and the maximum doses to the serial structures while the doses changes to the parotid could be significant. **Conflict of Interest:** This project is partly funded by SIEMENS.

SU-FF-T-421

The Influence of Field Length, Pitch, and Modulation Factor On the Quality of Helical Tomotherapy Plans

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Purpose: The planning process for helical tomotherapy plans is governed by three basic planning parameters: field length, pitch ratio, and

modulation factor. The purpose of this work is to evaluate the influence of each parameter on the achievable plan. **Method and Materials:** Using commercial treatment planning software (TomoTherapy, Inc.) the same head and neck case was re-planned by the same person using different planning parameters. The standard settings (field length of 25 mm, pitch of 0.287 and modulation factor of 2.5) were used to generate a baseline plan. Using the standard settings for two parameters the third parameter was varied for different plans. Three field lengths (10, 25, 50 mm), four pitch ratios (0.2, 0.287, 0.5, 1) and seven modulation factors were used (1.5, 2, 2.5, 4, 6, 8, 10). The plans were evaluated in terms of treatment time, target coverage, conformity, and sensitive structure sparing. **Results:** Increasing the pitch ratio leads to an increase in the volume of unspecified tissues that receives prescription dose (less conformal plans) and an increase in the dose to sensitive structures. The treatment time did not significantly reduce with increasing pitch (there are fewer gantry rotation but the gantry rotation period increases).
Similarly, an increased modulation reduces the dose to unspecified tissue and sensitive structures. However the cost is an increased treatment time. Using a larger field length increases the dose to unspecified tissue and sensitive structures while reducing the treatment time. All plans achieved acceptable target coverage and homogeneity. **Conclusions:** Changing the planning parameters mainly affects plan conformity. It appears that with respect to our standard settings a slight reduction of the pitch or a slight increase in the modulation factor should improve plan quality with a modest increase in treatment time. **Conflict of Interest:** One co-author is employed by TomoTherapy, Inc.

SU-FF-T-422

The Influences of Detector Energy Dependence and Perturbation On the Determination of Small Field Output Factors

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Purpose: In radiotherapy, accurate dose determination requires accurate measurements of output factors. The employment of small field size cones in radiosurgery imposes significant challenges for such accurate measurements, since the detector perturbation and its energy dependence, along with the detector size, may introduce significant errors in the output factor determination. This study investigated the impacts on the output factors introduced by the detector perturbation and energy dependence. **Method and Materials:** Output factors were measured on a Varian Trilogy™ linear accelerator for various collimator defined small square fields and twelve radiosurgery cones that were shipped with the machine. The measurements were performed by using four different detectors, namely, a pinpoint ion chamber, Koda EDR2 films, a stereotactic diode detector, and a pinpoint diode detector. The energy dependence was also evaluated for the ion chamber and diode detectors. **Results:** Both perturbation and energy dependence present non-trivial effects in the determination of the output factors. The impact of detector perturbation was more pronounced for the small fields, while that of energy dependence was evident for all the field sizes investigated. For a cone of 5 mm diameter, the perturbation introduced by using a PinPoint ionization chamber could result in almost 30% reduction in the output factor value. The deviations caused by the energy dependence varied from 3% to 6% depending on field sizes. **Conclusions:** The output factor measurements of small fields must not only account for the size of detector but also its perturbation and energy dependence to ensure the measurement accuracy for stereotactic radiosurgery.

SU-FF-T-423

The Limitation of Patient-Specific QA in IMRT with Detector Arrays

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Purpose: To investigate the limitations of patient-specific QA (quality assurance) procedures in IMRT plans for H&N and prostate cancer patients. **Method and Materials:** The detector array with 445 solid states diode detectors has been used to verify dose distributions obtained by a commercial RTP. The IMRT plans were generated using the Helios optimization algorithms with sliding window technique. It was calibrated according to the manufacturer-recommended calibration procedure. Then, it has been used to investigate (1) the accuracy of dose distributions with rectangular collimator settings, (2) a single field IMRT plan was generated to deliver uniform dose to a thin (2mm thick) square target imbedded in the center of the 30cm*30cm*30cm phantom, and (3) the patient-specific QA procedures for patients with prostate and H&N cancers. **Results:** (1)The differences between the plan and the measurements that are larger than "+/- 3%" for conventional rectangular collimator settings were observed along the X-axis. (2) The penumbras of a IMRT plan with a single field as a part of annual RTP QA routine procedure were investigated and the results were the same as the first case. These dose differences showed similar statistics as the case one. (3) With routine IMRT plan with 8 fields setup, the dose differences (the same definitions as above) shows the similar statistics as those of the second case, but observed to 94% -97% passing rate (with +/- 3mm DTA and +/-3% criteria). **Conclusion:** The limitations of the detector arrays are investigated and its effects upon the overall passing rates with the same criteria are found to be 3%-7%. But, the dose at the central axis of the routine treatment plans are within "+/- 2%" except in very special cases where the CA is very close to the high dose gradient regions.

SU-FF-T-424

The Measurement of Moving Tissue Maximum Ratio for Dynamic MLC Based Total Body Irradiation

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Purpose: Total body irradiation (TBI) with moving couch technique has been used in our clinic for years. Moving couch TMR for a field size has been acquired by multiplying TMR for a stationary beam and the 'm factor' defined as the ratio between moving phantom dose to stationary beam dose for same setup. The 'm factor' has been known to be field size dependent and not depth dependent. In order to replace lung and kidney blocks and achieve better dose uniformity using dynamic MLC, comprehensive understanding on the TMR for variable field sizes for an MLC leaf sequence is required. **Method and Materials:** A thorough measurement on the moving TMR has been performed. TMR's for field sizes of 5cmx40cm, 10cmx40cm, 15cmx40cm, 20cmx40cm and 30cmx40cm were measured both for the stationary and for the moving phantoms. Field sizes are defined at SAD 100cm and TMR's were measured at SCD 170cm for depths dmax to 34cm in 50cmx50cmx50cm water phantom with 6MV photon (21EX, Varian, Palo Alto, CA). **Results:** TMR's in moving phantom for different field sizes showed not more than 1% difference, while those of stationary phantom showed up to 34.8% difference for different sizes. The m factor which has been known to be a constant for a given field size rapidly increases after 15cm depth. Analysis of the data allowed us to understand the phenomena of measuring a point dose in a moving phantom. The key to the understanding was that both the phantom scatter and primary dose seen at the measurement position does not vary with field size when normalized to the reference condition. **Conclusion:** TMR's are independent to field size when couch is moving. This suggests that TMR variation does not need to be considered when designing the dose compensator with dynamic MLC for moving couch TBI.

SU-FF-T-425

The Potential for Dose Dumping in Normal Tissues with IMRT

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Purpose: To understand the potential for dose dumping in normal tissues (>85% of prescription dose) and to analyze effectiveness of techniques used in reducing dose dumping during IMRT planning. **Method and Materials:** We reviewed 249 IMRT plans for 53 patients with H&N, cervix and prostate cancers (6MV X-rays, 5-7F), to analyze in how many cases dose dumping occurred and types of techniques used to reduce dose dumping. Gantry angles, depth of beams, duration of optimization, severity of dose-volume-constraints (DVC) on normal structures, and spatial location of PTV were reviewed in relation to dose dumping. In addition, the effect of not contouring part of rectum in beam's path on dose dumping was studied. **Results:** Dose dumping occurred at Dmax depth in 16 pelvic cases (85%-129%). This was related to: 1) depth of beams, 2) narrow PTV and 3) reduced presence of rectum and bladder in beam's path. Dose dumping could be reduced to 85% by changing beam angles and/or DVC for normal structures in 4 cases and by creating phantom structures in 12 cases. Decreasing iterations also reduced dose dumping and MUs. Part of uncontoured rectum, if present in the field, received a higher dose than the contoured rectum with DVC, indicating that complete delineation of

normal structures and DVC is necessary to prevent dose dumping. In H&N, when PTV extends inadvertently into air beyond the body even by a few millimeters, dose dumping occurred in beam's path (170%, 7F plan). Keeping PTV margins within body contour reduced this type of dose dumping. **Conclusions:** Beamlet optimization, duration of optimization, spatial location of PTV and DVC on PTV and normal structures, with the potential to cause dose dumping, are an integral part of IMRT inverse planning. Use of appropriate technique/s would reduce the dose dumping and time needed to obtain optimum plan.

SU-FF-T-426

The Response of RadioChromic EBT Film in High-Energy Electron Beams

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Purpose: To describe the response of a new radiochromic film to high-energy clinical electron beams. GAFChromic® EBT film was designed primarily for verification of high energy photon IMRT treatments. It has been shown to be a very accurate and convenient photon detector. However, there is no literature on this film's response to high-energy electron beams. We initiated a study to characterize the response and utility of this film for routine electron beam dosimetry. **Method and Materials:** The linac was first calibrated to ensure that the delivered dose was known accurately. We exposed a series of EBT films at dmax in polystyrene to 6, 9, 12, 16, and 20 MeV electrons to develop standard characteristic curves. All films were from the same batch. We also exposed the EBT films in a solid water phantom to produce central axis depth dose curves. These data were compared against percent depth dose curves measured with either Kodak XV2 film in a solid water cassette, or in a water phantom using an IC-10 ion chamber or a PTW electron diode. **Results:** Results showed that the characteristic curve for this film was the same for electron energies from 6-20 MeV. Also, the response of the EBT film along the central axis of the beam matched the central axis percentage depth dose characteristics (R50, Rp) determined using Kodak XV2 film, electron diodes, and corrected ionization chamber measurements. **Conclusion:** GAFChromic® EBT film is shown to be an accurate detector for clinical electron beam applications. It is convenient to use since the solid water film cassette can be loaded in the linac room and requires no post-irradiation processing. It gives the same results for electron dosimetry as silver halide films, diodes, and ionization chambers. Research sponsored by International Specialty Products corporation

SU-FF-T-427

The Significance of Higher Dose Rates for Stereotactic Body Radiation Therapy

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The dose rate effect (DRE) has been much studied in the past, but has been less investigated in the simultaneously high fractional dose (HFD) and high dose rate (HDR) regime. These are circumstances akin to stereotactic body radiation therapy (SBRT) treatments. We have studied the possible significance of higher dose rates for SBRT fractionation regimens by analyzing model predictions based on the extensions of the linear quadratic (LQ) model and the lethal-potentially lethal (LPL) model. Previously reported data for seven human tumor cell lines have been used in this analysis. We have also analyzed possible modifications due to oxygenation for mixed populations of oxic and hypoxic cells. We have found that considerably higher cell kill levels are predicted to occur in the HFD and HDR regime for most of the cell lines that we have studied for both uniformly oxic and mixed cell populations. These model predictions suggest that some human tumor cells may exhibit significantly higher radiosensitivity in the HFD and HDR regime. This is pertinent to the implementation of SBRT and its fractionation regimens and, if shown to persist clinically, could lead to significantly higher tumor control.

SU-FF-T-428

The Use of a Commercial QA Device for Daily Output Check of a Helical Tomotherapy Unit

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Helical tomotherapy radiation therapy units, due to their particular design and differences from a traditional linear accelerator, require different procedures by which to perform routine quality assurance (QA). One of the principal QA tasks that should be performed daily on any radiation therapy equipment is the output constancy check. The daily output check on a Hi-Art TomoTherapy unit is currently performed utilizing ionization chambers placed inside a solid water phantom. This provides a good check of output at one point but does not give any information on either energy or symmetry of the beam, unless more than one point is measured. This also has the added disadvantage that it has to be done by the physics staff. To address these issues, and to simplify the process such that it can be performed by radiation therapists, we investigated the use of a commercially available daily QA device to perform this task. The use of this device simplifies the task of daily output constancy check and allows for this measurement to be performed by the therapists, rather than the physicist(s). This device can also be used to monitor the beam energy and lateral symmetry and can potentially be used to detect errors in the couch movement or laser misalignment.

SU-FF-T-429

The Use of a New Dynamic Motion Phantom for Patient Specific QA in Tracking Therapy

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Purpose: Respiratory gated/tracked radiation delivery with high tumor dose conformity is now a reality. This study aims to develop a patient-specific quality assurance procedure for 4D tracking delivery using patient-specific motion probability distribution functions and a dynamic motion phantom. **Method and Materials:** A commercial 4D motion phantom (CIRS, Norfolk, VA) was used in the study. A CT scan of the phantom was taken at a specific phase of motion. Patient motion trajectories during treatment were extracted using chest-wall LED markers and fiducials implanted inside target. To produce the patient-specific motion, a probability distribution function was generated from the extracted target motion trajectory. Sampled points from the probability function were input into the phantom motor controller, and patient treatment plan was delivered to the moving phantom with and without motion tracking. Dose distributions can then be compared with the original static plan calculations. **Results:** The tumor motion probability function for a 36-minute delivery showed significant differences from a 5-minute snapshot of tumor motion, with a median of 0.64 mm vs. 1.98 mm in the S/I direction, 0.56 mm vs. 1.22 mm, and 0.28 mm vs. 0.83 mm for A/P and R/L, respectively. The variances for the S/I direction were 5.58 mm vs. 7.24 mm, 0.98 mm vs. 0.84 mm, and 4.82 mm vs. 5.66 mm for A/P and R/L, respectively. A study of target motion compared with center of mass motion also showed significant differences, particularly in the S/I and R/L directions. Results of dose comparison with/without 4D tracking will be presented. **Conclusion:** A tumor probability distribution function is a more accurate representation of tumor motion than the center of mass method. To conduct patient-specific QA for 4D tracked dose delivery, it is more accurate to use the probability distribution and a programmable motion phantom is an excellent tool for this,

SU-FF-T-430

The Use of Fricke Solutions to Assess Light Dose in Photodynamic Therapy

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Purpose: To study the response of a Fricke solution doped with Photogem® to laser beams and light emitting diodes due to reactive radicals produced in Photodynamic Therapy (PDT). **Method and Materials:** The Fricke solution was prepared with 0.392 g of ferrous ammonium sulphate, 0.060 g of sodium chloride, 22 mL of sulphuric acid and made up to a volumetric flask of 1,000 mL with Milli-Q water. The Photogem®-doped Fricke solution was prepared by adding 0.0015 g of Photogem® to 1 liter of Fricke solution obtaining a concentration equivalent to what is employed for photodynamic therapy of tumors (4 mg/l). The solution was irradiated with laser beams and light emitting diode using radiant exposures up to 1300 Jcm^{-2}. The effect of laser irradiation on the solutions was evaluated by spectrophotometric technique. **Results:** Examination of spectrometric data have shown that Fricke solutions doped with Photogem® present a linear increase in their optical density at 304 nm as a function of the radiant

exposure of light sources which ranged between 514 and 640 nm. The efficiency of producing Fe^{3+} is dependent on the wavelength of the laser, being higher at 514 nm where this photosensitizer has the highest absorbance. **Conclusions:** The results obtained in this work indicate that Photogem®-doped Fricke solution may be used in PDT quality assurance to verify the consistency of the light sources and the photosensitizer solution used in a given treatment. The use of this method to quantify the combined effect of the interaction of light beams with photosensitizers in different protocols is discussed. It is hypothesized that a possible relation exists between the efficacy of PDT to the concentration of ferric ions formed in the Fricke system.

SU-FF-T-431

Time Delay Study of a CT Simulator in Respiratory Gated CT Scanning

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Purpose: To evaluate the time delay in respiratory gated CT scanning and its effect to motion synchronized radiotherapy.

Materials and Methods: In this study, we presented a technique to measure the time delay of AcQSim CT simulator (Philips Medical Systems) using Varian's Real-Time Positioning Management (RPM) system (Varian Medical Systems). A respiratory gating platform (REF 91150, Standard Imaging, Inc.) was first set at the position of amplitude maximum (Phase 0). Then a ball of 1.3 cm diameter was put on the platform and set at the CT laser. A single axial-scan was acquired across the center of the ball without motion. Then the motion was turned on and single axial-scans gated at different phases were acquired with a very narrow gating window. The time between the phase giving a good estimate of the ball and Phase 0 is the overall delay time. The delays were also verified using metal balls of 1.5 mm diameter initially set at the amplitude minimum (Phase 180).

Results: We found that for AcQSim CT, the overall delay for a single axial-scan (with 1s-scan time) is 1.75s. For multiple axial-scans, the overall delay is 1.75s for the first scan and 0.75s for the subsequent ones. This demonstrated that the CT mechanical startup delay is 1s. After the first axial-scan, the overall delay per scan is less because CT gantry continuously spins and no mechanical delay exists. We call the overall delay without the mechanical part the scanning delay, which basically equals to half the scan time (0.5s for 1s-scan time) plus the gating pulse triggering delay (250 ms). **Conclusion:** It is the scanning delay rather than the triggering delay that should be compensated when doing motion synchronized radiotherapy. The current interface between the RPM system and the AcQSim CT does not compensate for this delay.

SU-FF-T-432

Time-Delay Measurement of a Varian Real-Time Position Management System

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Purpose: Respiratory gating systems have been developed to reduce treatment uncertainty caused by organ motions related to respiration. The time-delay between when the gating signal is triggered and when the beam is turned on may affect the actual radiation dose delivered. In this study, we investigated the time delay for a Varian real-time position management (RPM) respiratory gating system. **Method and Materials:** A motion phantom with infrared markers was used to simulate a respiration signal. A small metal target ball was also attached to the phantom. An infrared camera was used to observe the motion of the phantom and to plot out a true motion curve. A narrow 2% phase gating window was set at various phases of 0%, 10%, 20%… and 90%. Electronic Portal Vision images were taken with a Varian Linear Accelerator at various phases of the simulated breathing cycle, and the location of the target ball was then plotted verses time to give a measured motion curve. The shift in time between the RPM gating signal and motion curve from portal imager was then measured to determine the time delay in the gating system. **Results:** The time-delay in Varian's gating system was found to be 0.0173 seconds. **Conclusion:** This work shows that there was a short time delay between the gating signal and the time when the radiation beam is turned on. The effect of time-delay on patient dosimetry needs to be further investigated.

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SU-FF-T-433

TMR Ratio Method to Correct for SSD Changes in Prostate IGRT with IMRT Delivery

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Purpose: In IGRT, couch shifts are needed to align the target to account for organ motion. In some rare cases treatment SSD may differ significantly (up to 1.0 cm) from the plan after these shifts. TMR ratio method is proposed to correct SSD changes so dosimetric accuracy of IGRT with IMRT delivery can be preserved. **Method and Materials:** A prostate patient CT was contoured in Eclipse TPS (Varian Medical Systems, v7.3) as test body. A bolus was added surrounding the body with either 1.0 cm or 2.0 cm thick bolus, (simulating 1.0 cm and 2.0 cm SSD change, respectively). An IMRT prostate clinical plan using 18 MV photons was exported to each of the three test bodies to create verification plans. TMRs were then read from our clinical data table according to different depths in the three test bodies. The TMR ratios were generated based on the non-bolus plan. To apply the TMR ratio to the beams, the prescription percent isodose line in each plan was lowered by the corresponding TMR ratios to increase MUs. By doing this, all other treatment parameters, including dynamic MLC configuration were kept the same. The corrected plans were exported to corresponding bodies and doses were calculated. The DVHs of prostate and critical organs were then compared. **Results:** DVHs for prostate and critical organs were identical for all three scenarios after TMR ratio correction. **Conclusion:** The TMR ratio method was applicable for IMRT plans to correct for small SSD changes in IGRT. For regular IMRT plans, if SSD changes are caused by other reasons like weight loss, this method is still valid assuming PTV does not change. However, if SSD change is larger than 1.0 cm, it is prudent to re-CT scan the patient and re-calculate plan because the PTV might have changed.

SU-FF-T-435

Tongue and Groove Effect in Direct Aperture Optimization IMRT Plans

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Purpose: Direct Aperture Optimization (DAO) is a promising new IMRT technique whereby the MLC leaves and relative weights of the apertures are simultaneously optimized. Due to the stochastic nature of the simulated annealing optimization algorithm, MLC leaves can have positions that are significantly different from their neighboring leaves. Opposed adjacent leaves with these positions can lead to a "ripple" in the dose distribution due to tongue-and-groove effect (TGE). In this work, we attempt to quantify the magnitude of the effect and commission the Pinnacle planning system to account for it. **Method and Materials:** To quantify TGE, we generated a two-segment beam: one segment with every other leaf on one side extending well past the central axis and the other with every other opposed adjacent leaf extending well past the central axis. Jaws set to 20x20 bound both segments and both had equal monitor units. This beam was delivered to a flat phantom with a film placed at 10cm depth.

Newer versions of Pinnacle (7.4 or greater) take into account TGE. This is modeled in the physics tool with a tongue-and-groove step parameter. We systematically changed this parameter and compared the resulting dose distributions to the film measurement.

We imported DAO IMRT plans into the Pinnacle planning system and compared the dose distributions with and without TGE. These were also compared with verification measurements. **Results:** The film displayed a 23% variation from minimum to maximum dose. The Pinnacle step parameter of 0.3cm reproduced the variation. If TGE is not accounted for in the planning, an underestimation of the absolute dose is observed for DAO IMRT plans. The magnitude of the underestimation is dependent upon the aperture shapes. **Conclusions:** TGE affects the dose distribution for DAO plans. Limiting the distance adjacent leaves may travel can reduce the effect of TGE.

SU-FF-T-436

Tools for Integrating Monte Carlo Dose Engines with a Radiotherapy Planning System

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Purpose: Monte Carlo simulations represent the gold standard in radiotherapy dose calculation. While numerous tools have been developed to facilitate accelerator and patient modeling within a Monte Carlo simulation, there are few commonly available tools for interfacing a Monte Carlo dose engine with a fully-featured treatment planning software package. We report on the development of tools to integrate a Monte Carlo dose engine with clinically useful radiotherapy planning software. **Method and Materials:** The initial release is configured to operate with PLanUNC, a freely available open-source radiotherapy planning tool. The Monte Carlo integration package consists of several modular scripts and programs that act as a bridge between the treatment planning software and the Monte Carlo dose engine. **Results:** Using PLanUNC as a front end for the Monte Carlo, the user can develop a treatment plan, export beams and patient information to the Monte Carlo, recover the dose distribution, and analyze the results of the calculation in PLanUNC according to isodose, DVH, or EUD, as well as compare the results of the Monte Carlo simulation with results from other calculations. **Conclusion:** The Monte Carlo interface package facilitates the clinical use of Monte Carlo by allowing a fully-featured radiotherapy planning suite to be used as a front end, allowing flexible treatment planning and analysis of the Monte Carlo results. The modular nature of the software makes it straightforward to adapt these tools for use with other treatment planning software packages.

SU-FF-T-437

Total Skin Electron Beam Commissioning with EBT Film

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Purpose: To investigate the usefulness of ebt film (a high sensitivity self-developing radiochromic film) in the commissioning of an accelerator based electron beam for total skin irradiation. **Method and Materials:** Measurements were made with ebt film in both water and solid water and compared with parallel plate ionization chamber measurements made in a small rectangular water phantom to determine calibration and depth dose characteristics. The ebt film was wrapped around the outer and inner plastic surfaces of a cylindrical water filled container to study the relationship between calibration measurements in the rectangular phantom and the surface dose characteristics from simulated clinical treatment. **Results:** The ionization chamber measurements agreed well with the film measurements. In the rectangular phantom surface dose measured about 80% of maximum dose. In the simulated clinical treatment dose was highest at the surface of the cylinder and ranged from approximately 2.5 to 3.5 times the dose at maximum from a single cylinder orientation compared with the six orientations used for the clinical simulation. Minimum and maximum clinical dose versus depth curves merged at a depth of about 5 mm. **Conclusion:** The film was found to be quite easy to use and produced results with less than the anticipated effort for this type of commissioning. It was found necessary to install UV filter sleeves over room fluorescent lights to minimize UV fog to low dose areas of the film

SU-FF-T-438

Treatment Planning Study of Prostate Cancer IMRT with a Flattening Filter Free Accelerator

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Purpose: IMRT is a common treatment modality for prostate radiotherapy. With IMRT, the optimization of the fluence map renders the flattening filter unnecessary. Flattening-filter free therapy for IMRT has been investigated recently, but clinical evaluations have not been conducted. In this study we compare IMRT treatment plans for prostate therapy generated with and without a flattening filter. Methods and Materials: IMRT plans were generated at 6MV for 4 early stage prostate patients using clinical dose prescriptions. Plans were generated with Eclipse 8.0 (Varian Medical Systems), which we commissioned with beam data measured on a Clinac 21EX operated with and without the flattening filter. For each patient two plans were generated, one with and one without the flattening filter. The plan DVHs were normalized so 98% of the PTV received 75.6 Gy. **Results:** Plans using the unflattened beam required 2 times fewer monitor units (on average) than plans using the flattened beam. Treatment plans using the unflattened beam had more homogeneous PTV coverage. The average maximum dose was 81.0 (0.6) Gy for the unflattened beam and 84.2 (0.6) Gy for the flattened beam. The average minimum dose was 70.5 (0.8) Gy for the unflattened beam and 71.2 (0.8) Gy for the flattened beam. DVHs showed nearly identical doses to critical structures between flattened and unflattened treatments. **Conclusion:** Clinically acceptable IMRT plans for prostate cancer can be developed with unflattened beams. They require substantially fewer monitor units than comparable treatments with conventional flattened beams while generating more homogenous PTV coverage. **Conflict of Interest:** Research sponsored by Varian Medical Systems.

SU-FF-T-439

Treatment Planning to Achieve Skin Sparing with Tomotherapy

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Purpose: To determine the extent to which skin dose can be reduced by defining the skin as a Region at Risk (RAR) structure to an IMRT treatment plan of a head and neck patient being delivered with a tomotherapy unit. **Method and Materials:** The head and neck section of a RANDO phantom was imaged in a CT scanner and two treatment plans were created for it simulating the treatment of a head and neck cancer. Both plans were identical, with the exception that for one an attempt was made to spare the skin as much as possible without compromising the tumor coverage or increasing dose to other RARs. This was accomplished by defining the skin as a RAR, for the purpose of pan optimization. In order to confirm the doses predicted by the treatment planning system the RANDO phantom was treated as per the plans, with metal oxide-silicon semiconductor field effect transistors (MOSFETs) placed on its surface to determine the dose. **Results:** The DVHs created by the treatment planning system showed a substantial reduction to skin dose as a result of introducing a skin RAR. The dose coverage of the PTV and other RARs were comparable. The change in skin dose was confirmed by the readings from the MOSFET detectors which indicated that the skin dose per treatment could be reduced from ~180 cGy to ~150 cGy with this process. **Conclusion:** The dose to the skin for head and neck treatments delivered with IMRT is known to be greater than that of conventional radiation therapy. We propose a method of delivering IMRT on a tomotherapy unit with substantial skin sparing. In order to control the skin dose to the patient, treatment plans must be made treating it as an organ at risk.

SU-FF-T-440

Treatment Table Induced Dose Perturbation in An IMRT Treatment

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Purpose: Treatment table support bars create problems in treatment planning and delivery. It is a complex issue for the case of IMRT with multiple and varying size beamlets. Methodology to account for the dose perturbation due to the presence of the table support in IMRT treatments is presented. **Method and Materials:** Five patients were planned with 7-beam IMRT using a posterior field and six other fields spaced at equal gantry angles. Treatment plans were optimized to produce suitable dose distributions for patient treatment. Plans were imported to solid phantom for dose verification. Treatment plan verification with ion chamber and film was carried out with and without bar. A mathematical weighted dose calculation is presented based on the equation: Dose = TD * [(MU-ΣMUij*T)/MU)], where TD is total prescribed dose, MU is total monitor unit from all beams, MUij is monitor unit in ith beam and jth beamlet that is blocked through the bar, and T is the measured transmission factor through bar. T was measured at 90 cm SSD at a depth of 10 cm for all photon energy and a film profile was taken. **Results:** Measured transmission through the center of the Siemens table bar for 6 MV and 18 MV was found to be 72.9% and 78.8% respectively. Even though IMRT beamlets pass through the bar, the dosimetric effect is minimal. Measured and calculated doses through bar for all clinical cases show agreement within ±4.5%, which is within the limits of the IMRT criterion. **Conclusion:** IMRT planning and treatment should be coordinated carefully to avoid passage of the beam through treatment table supports to avoid underdosage of the target area. However, in an accidental situation,

methodology presented here provides simple and accurate dose estimates for an IMRT treatment.

SU-FF-T-441

Updated Solid Water™ to Water Conversion Factors for 125I and 103Pd Brachytherapy Sources.

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Purpose: The updated TG-43U1 recommends determination of the consensus of low energy brachytherapy source parameters using experimental and Monte Carlo Simulated data. As per this recommendation, the measured parameters in Solid Water™ are converted into water data for clinical application. However, the published conversion factors may have been obtained using Monte Carlo simulations with a cross section files that may have errors for low energy photons, and also for inaccurate chemical composition of the phantom material. In this project impact of different calcium composition in Solid Water™ phantom on dose rate constant, radial dose function of ^{103}Pd and ^{125}I brachytherapy sources have been investigated. **Method and Materials:** Conversion factor of Solid water™ to water has been determined using MCNP5 Monte Carlo code. In these simulations two different calcium compositions in Solid Water™ of 2.3% (SW_a) and 1.7% (SW_b) were utilized. Monte Carlo simulations were performed for ^{125}I sources, with and without silver marker, in order to investigate the impact of characteristic x-rays (emitted by silver marker) on dosimetric parameters. However, the simulation for ^{103}Pd was performed only on one type of the source. Each simulation was run for a total of 20M histories to keep statistical fluctuation less than 0.3%. **Results:** For 2.3% calcium content phantom material the calculated conversion factor was found to be 1.027 and 1.045 for ^{125}I and ^{103}Pd sources respectively. However, for 1.7% calcium these values were found to be 0.989 and 0.963, respectively. **Conclusion:** The Solid water-to-water conversion factors for ^{125}I and ^{103}Pd sources are found to be 0.989 and 0.963 respectively as compared to the published value of 1.05 and 1.048. In addition, presence of silver marker had no significant impact on conversion factor for I-125 sources. Moreover, conversion for g(r) was also introduced for clinical application of measured data.

SU-FF-T-442

Use Of A 2D Array Of Diodes To Test The Accuracy Of MLC Leaf Position And Gap Width

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Purpose: For MLC-modulated IMRT fields, it is important that the leaf positioning be accurate and that the gap between opposing leaf pairs be precisely set. One test of the MLC is the "picket fence" pattern, which consists of narrow, sequentially delivered, abutting sub-fields of radiation. Typically in current practice, a radiographic film is irradiated and visually inspected for a discontinuous radiation pattern. Here, a 2D-array of 455 diodes (MapCheck, Sun Nuclear, Melbourne, FL) was used to detect the radiation pattern. **Method and Materials:** The array was oriented such that 120 diodes aligned with the center of the MLC leaves at each of their sub-field edges. Measurements were compared against a dose distribution calculated by the XiO treatment planning system (Computerized Medical Systems, St. Louis, MO) for a picket-fence segment pattern delivered to a flat phantom. MapCheck software was used to obtain the relative percent difference, normalized to the center diode, between the 455 diode-measured and calculated points. Spreadsheet software was written that extracted the desired 120 sample points from the 455 measured points and performed routine data analysis in less than 30 s. **Results:** Four different Siemens accelerators equipped with 29-leaf pair MLCs were measured over a two-month period. By careful adjustment of MLC leaves, the percent difference between measurement and calculation, averaged for 120 points, could be kept within ±5% with a standard deviation of 6.0%. This standard deviation is attributable to individual MLC leaves and deviations in leaf position for various set positions across the field. The trial-to-trial variation is about 2% for the average difference for the 120 points. A 1-mm leaf offset in the picket fence delivery corresponded to an average difference of about 17%. **Conclusion:** A rapid, quantitative method, sensitive to sub-millimeter changes in MLC leaf positioning and gap width has been devised.

SU-FF-T-443

Use of Minimum Intensity Projection for Target Volume Delineation in 4D-CT Using Contrast for Liver Cancer

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Purpose: To investigate the use of the minimum intensity projection (minIP) methodology for the accurate and rapid generation of internal target volumes (ITVs) in four-dimensional CT (4D-CT) scans using IV contrast for Liver Cancer. Single (4D-CT) scans reliably capture intra-fractional tumor mobility for radiotherapy planning, but generating the ITVs requires the contouring of gross tumor volumes (GTVs) in up to 10 respiratory phases. The use of maximum intensity projection (MIP) protocols for the generation of ITVs in Lung has been recently shown to be reliable, but cannot be used for Liver due to the use of contrast agents. **Method and Materials:** We obtained the 10-phase ITVs using the 4D-CT data sets contoured by one physician using Pinnacle. The ITVs generated from the minIP volume data sets were determined by automatic contouring. Comparison of the ITVs was performed by focusing on the tumor volumes and voxel positions. **Results:** The results showed that the differences in the tumor volumes were slight in the lower lobe of the liver. In the upper lobe of the liver, however, we observed a significant difference in tumor volumes between the ITVs. This is because the minIP algorithm systematically chooses the lowest CT value in each 10-phase voxel set, which leads to a preferential selection of lung tissue over liver tissue in the diaphragm region. In the lower lobe of the liver, the tissue is basically liver or tumor, and so tissue selection should generally not be as complex. **Conclusion:** The minIP algorithm has not been shown to be robust for the delineation of liver tumors located near the top of the diaphragm. In the rare occasion where there is bowel including gas is located near the liver tumor, we predict the minIP may also be inadequate for the tumor delineation.

SU-FF-T-444

Use of the Gamma Index to Evaluate the Dosimetric Characteristics of X-Rays Beams in Radiotherapy: Implementation to a LINAC Monte Carlo Simulation

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Purpose: From IEC 976 and 977, the dose distributions quality for x-rays beams from LINAC gets through the fulfilment of four parameters. This work is aimed at replacing these dosimetric tests by one parameter (gamma index) and using this concept to validate Monte Carlo simulated beams. **Method and Materials:** From measurements of a 12 MV beam of a medical LINAC, analytical functions have been set to fit reference depth-dose and profile distributions. Then, those 1D distributions have been altered to reach the admissible limits of the IEC standard criteria. The peculiar tolerance criteria of the gamma index have been determined by comparing altered and reference distributions. This 12 MV beam have been simulated with the Monte Carlo code PENELOPE for different incident electron configurations at the target. The simulations have been fitted with polynomial functions to get better resolution before being compared to measurements using the gamma index to avoid false positives or false negatives due to a lack of spatial resolution in these simulations. **Results:** The tolerance criteria for the gamma index have been determined experimentally by comparison with the IEC standard requirements. They are more restrictive by nature than the IEC criteria. This unified concept of dosimetric tests by the systematic use of the gamma index enabled us to select effectively the parameters for the beam simulation. **Conclusion:** This work shows the possibility of using only one test for all the measurements required for x-rays beam QA and its Monte Carlo simulations. In the future, this work will lead to the implementation of a set of simulations in order to replace measurements required for the quality control of the Treatment Planning System. Evaluation tests should be based on the calculation of the 3D gamma index to simplify test processes.

SU-FF-T-445

Use of the Monte Carlo Method as a Comprehensive Tool for SMLC and DMLC-Based IMRT Delivery and Quality Assurance (QA)

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Purpose: To report on use of a thoroughly benchmarked MC dose calculation algorithm as an accurate tool for IMRT delivery and QA, in patient-like media, where direct measurements for routine QA are impractical. **Methods and material:** We have developed a source model to investigate dosimetric effects related to MLC based delivery techniques such as step-and-shoot and sliding window using the DPM MC code. The model incorporates details of the Varian, 120-leaf MLC and has been comprehensively verified against measurements in homogeneous and heterogeneous phantoms. As part of this development, we have investigated an efficient algorithm, using adaptive kernel density estimation for sampling phase space files. Using this accurate source model, we have studied beams that were sequenced with 1% and 10% fluence intervals for prostate, brain, head and neck and breast IMRT beams. Dose differences between SMLC and DMLC delivery types were evaluated in homogeneous and heterogeneous media (bone, lung and low-density slabs) using DPM. We have also investigated dosimetric differences between optimized planned leaf sequences and actual delivered sequences, using machine log (Dynalog) files, which capture the physical leaf positions during delivery. **Results:** Benchmarking of the source model showed average agreement with measurements within 1%/2 mm. For a given fluence interval, calculated dose differences between SMLC and DMLC delivery techniques are different in homogeneous and heterogeneous media. Dose differences of up to 10% were found between plans developed with 1% and 10% fluence intervals for either SMLC or DMLC delivered sequences. Calculated dose differences of up to ±3cGy were observed between planned and delivered sequences (computed using the Dynalog files) for a prostate beam; these differences were in good agreement with film measurements. **Conclusions:** A well commissioned MC-based dose algorithm provides a useful tool to study dosimetric issues related to fluence modulation and static versus dynamic delivery in IMRT.

SU-FF-T-446

Using Mini-Verification Films in Clinical Practice

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Purpose: To present a clinical example of finding field matching errors in a supine three-field cranial-spinal irradiation technique utilizing mini-verification films. **Method and Materials:** A three-field Cranial-Spinal Irradiation technique uses right and left lateral head fields and one or more PA spinal fields. The table and collimator are rotated in order to match the three fields at the three-field junction. Verification simulation films are taken to verify adequate block design and field localization. Lead markers are placed on the patient's immobilization mask at the field junction. Portal images are taken and reviewed. In a darkroom, EDR2 (Kodak) film is cut into a 10cm x 20 cm rectangle, placed in an opaque paper jacket and sealed with black tape. This "mini-verification film" is taped onto the patient's headrest and the patient is placed supine with the $C_{2\text{-}5}$ vertebral-body level over the film. An immobilization mask is then placed over the patient's head. The mini-film is exposed by all three fields during dose delivery. The film is developed and reviewed immediately. **Results:** Using mini-verification film, a field overlap was immediately detected on a patient. Under closer review of the port film, the spinal field was superior to the lead markers at the junction. This mismatch was subtle and not immediately obvious. However, the overlap was striking on the mini-verification film. **Conclusion:** Field matching in three-field Cranial-Spinal irradiation is critical to avoid underdosing or overdosing the spinal cord. Numerous checks and balance systems should be in place to avoid such field mismatching. The example presented illustrates the effectiveness of the mini-verification film to discover the overlap. The use of the mini-film provided immediate and conclusive evidence of patient mistreatment.

SU-FF-T-447

Utility of Film Dosimetry for Assessing TomoTherapy Treatments of Superficial PTVs

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Purpose: To assess the utility of film dosimetry in a cylindrical polystyrene phantom for evaluating the accuracy of dose calculated by the TomoTherapy HI·ART treatment planning system for superficial planning target volumes (PTVs). **Method and Materials:** A TomoTherapy treatment plan was developed for a superficial PTV (1-cm deep radially by 90º azimuthally by 4.2-cm longitudinally) contoured on a 27-cm diameter by 37.4-cm long cylindrical white opaque polystyrene phantom. The phantom included two removable planar film cassettes, one perpendicular to and one including the cylinder's axis. Kodak EDR2 film was cut using templates, resulting in film edges coinciding with the phantom surface (±0.25-mm). The axial film was irradiated according to the TomoTherapy plan then the phantom was translated longitudinally and the sagittal film irradiated. The films were scanned with a Vidar film digitizer, converted to dose, and the common depth-dose curves compared. Measured axial and sagittal dose distributions were compared with those calculated. **Results:** The common depth-dose of the axial and sagittal films agreed well, although the axial film had a lower relative dose by 2.5%. Comparisons of measured and calculated dose on the axial film showed agreements to within 5% at depths greater than 3-mm. At shallower depths, doses showed larger differences but distance-to-agreement values were small (<2mm). These differences could be due to planned to delivered dose alignment techniques and/or the film cutting process, which is under investigation.**Conclusion:** Orthogonal films irradiated in a cylindrical polystyrene phantom produced common depth-dose curves that agreed well. Future comparisons with thermoluminescent dosimetry should confirm the utility of EDR2 film for a comprehensive study of the accuracy of the TomoTherapy treatment planning system for planning treatments of superficial PTVs normally treated with electrons.

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SU-FF-T-448

Validation of a New Photon Dose Calculation Model--Analytical Anisotropic Algorithm

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Purpose: To validate a new photon dose calculation model Analytical Anisotropic Algorithm (AAA) on Eclipse™ treatment planning system (TPS). Comparison of AAA dose calculation was performed with measurements and other two conventional algorithms, Pencil Beam Convolution (PBC) algorithm on Eclipse™ and Collapsed Cone Convolution/Superposition (CCC) algorithm on Pinnacle$^{3.0}$ TPS.
Method and Materials: Four phantoms were CT scanned and the image set was imported into both TPS for dose computation and analysis. The four phantoms were: 1) homogenous tissue equivalent phantom, 2) tissue equivalent phantom with infinite lung heterogeneity, 3) tissue equivalent phantom with finite lung, 4) IMRT dose verification phantom. Measurements were made by exposing the phantom using Varian Linac. Point measurement and film measurements were compared with calculated results from the three algorithms. Dose responses for high and low energy photon beams were investigated for several different depths and PDD curves were compared in the phantom for various field sizes. The IMRT plans were generated by both TPS and were performed on the IMRT phantom to compare fluence maps. **Results:** AAA dose prediction fits the film measurements well except that there is up to $\pm 6\%$ discrepancy for dose profile perpendicular to the interface of tissue and lung. Point measurements support the AAA algorithm calculations. AAA also accurately predicts the decrease in PDD curves due to the lung inhomogeneity for 6MV energy. For the high energy photon beam and very small field size (2cm*2cm) in lung region, AAA prediction is up to 8% lower than the measurements. **Conclusion:** AAA algorithm accounts for attenuation corrections and electron transport, and models the deposited dose in the lung with greater accuracy than PBC. It is also faster than CCC algorithm. AAA algorithm can not accurately model the lateral scattering

in tissue heterogeneity, but it can still give a reasonably close (within $\pm 6\%$) prediction.

SU-FF-T-449

Validation of a Plan-Based Calibration Method for Relative Dosimetry of IMRT

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Purpose: Validation of a new "plan-based" image calibration method for IMRT relative dosimetry comparisons. **Method and Materials:** Radiological Imaging Technology image analysis software (version 4.2) contains a new calibration routine called plan-based calibration (patent pending). After registration of a 2-D dose image from the planning system with a measured but uncalibrated dose image, the routine then maps the planning system doses to each film or CR image pixel value and constructs a calibration curve. This calibration curve is then applied throughout measurement image to convert all pixels to dose. Because it does not use an independent dose vs. pixel calibration, it can be used for relative dosimetry only. Ten IMRT cases were studied for which both conventional dose calibration using parallel irradiation of film and the plan-based calibration were used. The Gamma value was used as a measure of agreement where 3% dose and 3 mm distance to agreement were set as tolerances. For these same cases, a 5 mm registration error was introduced and the comparison repeated. **Results:** In all properly registered cases, the plan-based calibration had fewer pixels with Gamma >1 than did the conventional calibration. Overall, the plan-based method gave 50% fewer pixels with Gamma > 1 than did the film-based calibration. This may be due to additional errors of the film calibration process convolving with intrinsic planning system, phantom setup, and film processing and scanning errors. The plan-based calibration was equally able to detect the registration error by giving a similarly large increase in percentage of pixels with Gamma >1.
Conclusion: These data suggest that the plan-based calibration method provides a more accurate comparison of the measured vs. calculated dose distribution than conventional calibration methods using less time and materials. **Conflict of Interest:** This research was supported by Radiological Imaging Technology.

SU-FF-T-451

Verification of a Proton Treatment-Planning Pencil-Beam Dose Algorithm with Monte Carlo

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Purpose: To verify the accuracy of a pencil beam superposition dose algorithm in heterogeneous media for proton therapy treatment planning system using Monte Carlo simulations. **Method and Materials:** A proton treatment planning system (ECLIPSE, Varian) was validated using dose distributions predicted with Monte Carlo (MC) simulations. The accuracy of the MC physics models was established in previous studies and the model of the therapy unit is described elsewhere (Newhauser et al, Zheng et al., separate contributions to this conference). MC simulations of proton beams with different range, field sizes and modulation widths into various phantom geometries, comprising cubic water phantoms with lung and bone equivalent material slabs, cylindrical inhomogeneities and non-flat upstream surfaces, were carried out to compare depth dose profiles, lateral profiles, penumbral widths and field size values to predictions from the treatment planning system. **Results:** More than 30 different beam configurations have been investigated. Range differences, and differences in the 80%-20% penumbras larger than 2 mm were observed twice, while differences in the 50%-50% field size were smaller than 1 mm. The range differences were not related to the inhomogeneities, but are due to differences in the proton stopping powers used in the MC and TPS systems. The deviations in the penumbras were mostly seen in the 90%-10% penumbra comparisons of profiles at large depths, where contributions from multiple Coulomb scattering started to become more visible in the MC simulations, but less in the TPS predictions. **Conclusions:** Monte Carlo simulations proofed to be a valuable tool to verify the dose predictions in heterogeneous phantoms from a commercial treatment planning system. The treatment planning software performed well in most cases considered. This investigation helped to substantially reduce the time required for testing and the treatment planning software package and provided valuable feedback to the TPS developer.

SU-FF-T-452

Verification of Cell Irradiation Dose Deposition Using Radiochromic Film

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Purpose: A standard technique for cell survival curve determination is based on the cell culture technique. Survival curve is reconstructed by plotting the fraction of surviving cells as a function of delivered dose. We describe a technique that irradiates all cells at once by using two wedges (static and dynamic wedge concurrently) on a linear accelerator whereby we irradiate the multi-compartmental dish to a desired dose range from 1 - 5 Gy. We also employed EBT model GAFCHROMIC^{TM} film to verify the dose delivered in each of the compartments within the dish. Our technique overcomes the problem of possible contamination during the re-plating after irradiation and all cells are kept under the same conditions.
Method and Materials: Cells, plated within a multi-compartmental (8 x 12) dish were irradiated using a 6 MV photon beam employing a combination of 60^o physical ("static") wedge and 60^o Enhanced Dynamic Wedge. A 10 cm by 12.5 cm piece of EBT film was positioned below cells. Spatial dosimetry was performed using the AGFA Arcus II document scanner. The change in optical density of the unexposed film piece was subtracted from the exposed film piece to obtain the final *netOD* that was converted to dose using previously determined calibration curve for the reference type dosimetry.
Results: Technique described delivers a dose gradient ranging from 1 Gy within the first compartment to 5 Gy within the last compartment. Maximum relative uncertainty of 2% was observed at 5 Gy.
Conclusions: In this work, we describe a technique using a combination of static and dynamic wedge to obtain doses necessary to reliably perform MTT Assay in a dose range from 1 Gy to 5 Gy within a multi compartmental dish. We have also described a method to verify the dose delivered using the EBT model radiochromic film.

SU-FF-T-453

Verification of Head Leakage as the Primary Source of Shielded Radiation From a Tomotherapy Unit

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Purpose: To investigate the adequacy of an existing 6 MV vault for shielding and to verify that head leakage is the primary source of radiation emanating from a helical tomotherapy unit. **Methods & Materials:** Before installation of a helical tomotherapy unit in an existing 6 MV accelerator vault, the vendor provided isodose plot was analyzed. Estimated exposure was calculated by scaling the exposure on the plot, correcting for inverse square, and using a 6 MV TVL for 2.35 g/cm^3 concrete from NCRP 49. Sinograms were generated for a rotational (20 second period) and fixed gantry (0°, 90°, 180°, 270°) to deliver radiation with all leaves closed and opened for a 5x40 cm^2 field size and fixed couch position. At 26 locations the exposure rate was measured at height of isocenter with an ionization chamber. **Results:** The maximum exposure occurred when the accelerator was nearest to the measurement point. A maximum exposure rate of 1.75 mR/hr was measured in the accelerator control area behind 30" concrete at a 45° angle relative to the axis of the accelerator and a distance of 5 meters. The lowest exposure rate at the same position occurred when the accelerator was at the farthest distance. Assuming 30 minutes of irradiation time per hour, the maximum exposure would be less than 1750 mR/yr. No significant differences (~10-15%) between field settings were observed. The calculated values are higher than the measured and loosely agree with the highest measured values at each position. **Conclusions:** The existing vault is adequately shielded for the tomotherapy unit. Data indicate that leakage is the primary radiation source. Modulation does not affect the leakage significantly. The calculated and measured values disagree and discrepancy may be attributed to the use of a 6 MV TVL.

SU-FF-T-454

Video-Coaching as a Biofeedback Tool to Improve Gated Treatments

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Purpose: Gated treatments using the Varian RPM–gating™ System include in a standard configuration a coaching tool based on voice commands ("breathe-in"/"breathe-out") called audio-coaching. As this configuration does not include feedback information like amplitude and breathing period, there are limitations concerning respiration depth and breathing pattern. The aim of this study was to evaluate the impact of video-coaching as biofeedback to improve gated treatments of breast cancer. **Method and Materials:** Varian RPM-gating system is used for acquisition of the CT-Scan (4D-CT) as well as the treatments; for the latter it manages the controlled switching of the radiation beam during a pre-selected specific phase of the respiratory cycle. 100 patients with gated treatments have been analyzed, whereas 50 were only audio-coached and 50 audio-coached with video-feedback. We evaluated periodicity and amplitude changes as well as compliance with regard to the theoretically calculated duty cycle and determined the dependency of the parameters on the coaching type. **Results:** For the CT acquisition several changes has been observed, i.e. amplitude fluctuations are significantly smaller (p=0.005) and the breathing curves are smoother. This leads to an increased compliance during the treatment course: almost all video-coached patients reached in average their theoretical duty cycle, whereas 60% of the patients with audio-coaching only had more than 25% longer treatment times due to inappropriate amplitudes. Periodicity is not dependent on the kind of coaching (p=0.01). **Conclusion:** Video-coaching is suitable to significantly improve the quality of 4D scans and allows optimizing the treatment time due to better compliance. In a next step we are currently implementing this feedback technology combined with deep inspiration breath hold technique thus allowing the patient to control the treatment themselves in a direct way. Preliminary results indicate that this approach could suit the individual patient need in a better way.

SU-FF-T-455

Volumetric Analysis of Dose Delivered by Xoft Axxent X-Ray Sources

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Purpose: To study the spatial characteristics of the dose delivered by the Xoft Axxent Electronic Brachytherapy system within a volumetric (voxel) visualization system. Further, to extend the study from tools available in treatment planning systems, which are typically limited to a single set of TG43 input data for a source type, to be able to investigate data for individual sources. Additionally, to allow for comparisons to be made between the standard or average source, and a particular source of interest via difference images, line plots, and histograms. **Method and Materials:** Input spatial data in the form of polar and azimuthal angular distributions, and depth dose readings acquired in the course of source characterization, were loaded into a custom LabVIEW program. This program created 3D voxel arrays for an average reference set and for individual sources, allowing two data sets in memory simultaneously. Analyses on the voxel arrays include visualization of the distributions via 2D false-color images and line plots, scatterplots and histograms of values and cumulative values. The visualization tools can be applied to either source or reference data set or the difference between them. **Results:** 2D images representing slices through the volume, and line plots along chosen lines on the images, provide information on the spatial variation in either the source data or in the difference, or percent difference, between a specific source and the reference. Histograms provide quantitative results on the degree of variation between source and reference, while scatterplots provide insight into the region or characteristic causing variations. **Conclusion:** Volumetric analysis of the Xoft Axxent™ source is a powerful tool for understanding the dose distribution and expected variation from source to source, which can be applied to any brachytherapy source for which 3D spatial data is available.

SU-FF-T-456

What Is the Optimal Source-To-Collimator Distance for An Extendible MLC Designed for Energy- and Intensity-Modulated Electron Radiation Therapy of Superficial Tumors

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Purpose: To determine an optimal source-to-collimator distance (SCD) for an extendible multi-leaf collimator (exMLC) designed for energy- and intensity-modulated electron radiotherapy for superficial tumors. **Method and Materials:** To implement an extendible Modulated Electron Radiation Therapy (exMERT) technique for optimized radiotherapy of superficial tumors, we designed a virtual exMLC and investigated the effect of SCD on the characteristics of resulting electron beams. An exMLC made of tungsten leaves of 15 mm thickness and 5 mm width and with straight leaf ends was modeled as a MLC component module in EGS4/BEAM simulations. Phase space files were scored at the back surface of the exMLC and at 100 cm SSD for 6 to 20 MeV electron beams emerging from a Varian Clinac 21EX treatment head equipped with exMLC located at SCDs of 85, 90 and 95 cm. These phase space files were then analyzed using BEAMDP and used as beam input for further dose calculations in water. **Results:** At shorter SCD (85 cm), the in-air scatter and dose overlapping at depth were the worst compared to other SCDs. The 80-20 penumbra of 1 cm × 1 cm beamlet was 0.92 cm at 100 cm SSD and 1.35 cm at 2 cm depth in water for 6 MeV beam. On the other hand, the leaf scatter and leakage from the exMLC located at 95 cm SCD resulted in larger bremsstrahlung photon dose (~4% of maximum dose for 20 MeV electrons). Overall, the exMLC at 90 cm SCD yielded modest leaf scatter and leakage as well as dose overlapping at depths, acceptable to clinical applications of exMERT with good clearance for patient setups. **Conclusions:** Based on the consideration of beam penumbra, photon contamination, and patient clearance, the SCD of 90 cm was determined to be the best compromise for exMLC to be used in exMERT.

SU-FF-T-457

Whole-Body Dose for Helical Tomotherapy

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Purpose: Tomotherapy is a form of intensity modulated radiation therapy (IMRT) that utilizes rotating fan beams modulated by a binary-multileaf collimator. The radiation is delivered either serially or helically as the patient is moved in a craniocaudal sequence for tumor coverage. While Tomotherapy can deliver highly conformal dose distributions, it yields the lowest delivery efficiency (tumor dose per MU) of current IMRT-delivery options. This relatively low efficiency has the potential for delivering high total-body doses due to head leakage, so a quantitative evaluation of the whole-body dose is warranted. **Methods and Materials:** We conducted this evaluation for a dedicated helical Tomotherapy delivery device (Hi-Art System®, Tomotherapy Inc) and compared the results against the previously published serial Tomotherapy system (Corvus, NOMOS Corporation) and traditional IMRT whole-body data. A typical head-and-neck treatment plan (2Gy per fraction, 6622MU) was prepared and delivered to a large water-equivalent phantom. An ADCL-calibrated large-volume ionization chamber (A17 Exradin) was used to measure the low doses. The dose was measured at both 1.5cm (dmax) and at the center of the phantom. **Results:** From 10cm to 48cm from the inferior target edge (the most proximal serial tomotherapy point was at 10 cm), the helical tomotherapy dose was less than 0.5% of the target dose, and was between 20% and 30% of the serial tomotherapy leakage dose. This study showed that the whole-body dose for the 70Gy is approximately 140mSv. This dose is less than the 560mSv for a 70Gy treatment as published by Followill, et al. (Int.J.Radiat.Oncol.Biol.Phys. 38, 667). **Conclusions:** This study indicates that the commercial helical Tomotherapy system provides less whole-body dose than serial Tomotherapy or conventional IMRT. This is probably due to the internal linear accelerator shielding design and the use of 6 MV photons.

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SU-FF-T-458

MC Simulations in Support of Developing and Testing An Analytical Dose Algorithm in Ocular Proton Therapy

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Purpose: To create a Monte Carlo (MC) model of an ocular proton therapy device, or ocular nozzle, that can predict relative doses to within 3% or 0.5 mm, *D/MU* values, and be used to develop and commission an analytical algorithm to predict doses and *D/MU* values to within similar criteria. Methods and Materials: Depth dose profiles and *D/MU* values were measured in eight ocular proton therapy fields including four unmodulated and four modulated beams using a parallel-plane ionization chamber in water. Crossfield profiles were measured at three or more depths for each of the modulated beams using film. A MC model of the ocular nozzle was constructed using the MCNPX radiation transport code. After benchmark tests against the measurements, the MC model was used to provide dosimetric data needed to develop a broad-beam algorithm capable of predicting relative and absolute doses and to test the algorithm's predictions more comprehensively than could be afforded with measured data. Specifically, MC and analytical predictions were calculated and compared in two-dimensions in a water phantom and in an anthropomorphic model of the eye. **Results:** Relative depth dose profiles between MC and measurements agreed to within 3% or 0.5 mm. MC predicted *D/MU* values agreed to within 1% of the measured values. Similarly, the analytical algorithm accurately predicted dose distributions where the predictions were generally within 3% or 0.5 mm of measured and simulated values at water depth > 6 mm. At shallower depths, the analytical model underestimated the dose by approximately 3% to 6%, which MC simulations revealed was due to edge-scattered protons from the nozzle's collimators. **Conclusion:** The MC model accurately predicted dose distributions and *D/MU* values in ocular proton therapy beams. Furthermore, the present work demonstrates the value of the MC method for developing and testing contemporary analytical dose algorithms.

SU-FF-T-459

An Implantable Dosimeter Study of Patients with Prostate Cancer

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Purpose: A study of 30 prostate cancer patients who received implanted radiation dosimeters in conjunction with external beam radiation therapy has been completed. The purpose of the study was to compare daily measured dose to the value predicted by the treatment planning system. **Method and Materials:** In most patients two dosimeters were placed adjacent to the capsule of the prostate. The devices were introduced perineally using a trocar/cannula system. Polyester mesh was placed behind the sensors after insertion to prevent them from moving back down the insertion track before healing occurred. Serial CT scans were taken to gauge any migration of the devices away from the point of surgical placement. Some patients were localized on a daily basis using a kilovoltage x-ray positioning system. The clinical protocol did *not* permit alteration of the therapy parameters based on sensor readings. **Results:** An evaluation of the dose discrepancy between measured and planned values was completed for each sensor. Additionally, the relative standard deviation of each sensor's readings was calculated (as a measure of randomness of the readings). In many patients, the relative standard deviation value exceeded 3%, which is beyond the nominal value for the sensor itself when tested in a phantom. In some patients the cumulative dose for a given treatment period disagreed with the planned dose by 5% or more. The discrepancy tended to be more pronounced for boost phases when the isodose contours were reduced in volume. **Conclusions:** This initial data suggests that implanted dosimeters may play a useful role in tracking dose discrepancies, both systematic and random, in patients being treated with external beam therapy for prostate cancer. Future studies will focus on the effects of daily kilovoltage x-ray localization, using the dosimeters as fiducial markers, on the magnitude and randomness of dose discrepancies.

Supported by Sicel Technologies

SU-FF-T-460

Comparative in Vitro Study of Cell Survival Following IMRT and Acute Dose Delivery

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Purpose: To investigate cell kill from IMRT fields compared to acute dose delivery. **Method and Materials:** Survival was assayed in vitro for three cell lines: Chinese hamster V79 fibroblasts, human cervical carcinoma SiHa and colon adenocarcinoma WiDr. An actual head and neck seven field dynamic IMRT plan produced for Varian iX, 120 Millennium MLC linear accelerator was used. The calculated IMRT dose (Cadplan, Palo Alto) to the point of irradiation in the acrylic phantom was 2.1Gy. This was verified by measurements with an IC10 ionization chamber. Two IMRT dose delivery scenarios were explored: 1. normal delivery, irradiation time of 5min 10s, and 2. IMRT delivery with a 5min break for MLC re-initialization after three fields were delivered, irradiation time of 10min. For comparison the same dose of 2.1Gy was delivered by parallel-opposed pair (POP) in 75s, 20s beam-on time per beam. Survival data were obtained in the dose range up to 10.5Gy to establish the linear-quadratic survival curves. **Results:** An increased cell survival following irradiation with IMRT fields was observed for all cell lines. V79 cells showed the smallest increase: 0.833±0.018 (95% confidence limits) from POP compared to 0.860±0.040 for IMRT with MLC re-initialization. This increase was very pronounced for the radiosensitive SiHa cell line: 0.390±0.046 for POP irradiation compared to 0.591±0.080 from IMRT requiring MLC re-initialization. Although variable between cell lines, projections made for a 30 fraction treatment showed substantial reduction in cell kill. **Conclusions:** We observed an increase in cell survival from IMRT fields compared to acutely delivered dose. This increase was persistent, but not always statistically significant. Projections for a fractionated treatment showed that consequences of this increased cell survival are substantial with a very large variation between cell lines. This projection, however, does not account for features present in vivo, for example reoxygenation and reassortment.

SU-FF-T-465

Relating Changes in Pulmonary Functin Tests (PFTs) to Changes in Radiation-Induced Regional Lung Perfusion

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Purpose: To further assess if RT-induced changes in pulmonary function tests (PFTs) can be prospectively predicted based on the sum of predicted RT-induced changes in regional lung perfusion. **Method and Materials:** Between 1991 and 2005, 123 evaluable patients with lung cancer underwent pre- and post-RT PFTs (forced volume capacity [FVC], forced expiratory volume in one second [FEV1] and diffusion capacity for carbon monoxide [DLCO]) as part of a prospective trial. Patients with recurrence or death within 6-month post-RT were excluded. The maximal declines in PFTs were noted. The anticipated decline in PFTs was computed by summing the predicted reductions in regional perfusion, throughout the lung, based on a previously-defined population dose-response model [DRC] and the patient's pre-RT SPECT (single photon emission computed tomography) lung perfusion scan. This "integrated response" is also termed the overall response parameter (ORP):

$$ORP = \sum_{d=0}^{dmax} (Vd \times Rd) \times 100\%$$

where *Vd* is the percentage volume of lung irradiated to dose *d*, and *Rd* is the predicted reduction in regional perfusion at dose *d* based on a population DRC. Correlations between predicted and measured changes in PFTs were evaluated using 2-tailed Pearson test. **Results:** There was a statistically-significant association between the reduction in PFTs (i.e. FVC and DLCO) and ORP, $p<0.01$; however, correlation coefficients were low (range: 0.24-0.35). Correlations were better in the subgroup of patients without large central tumors (i.e. those often with associated hypoperfusion of adjacent lung on the pre-RT SPECT) and with more than 2 follow-up PFTs post-RT (range: 0.41- 0.62). **Conclusion:** The sum of

predicted RT-induced changes in regional perfusion is related to RT-induced changes in PFTs, however, correlations are relatively weak. These findings are consistent with our prior analysis involving fewer patients and continue to illustrate that predicting changes in PFTs is extremely challenging.

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SU-FF-T-466

A Single Dose Calibration Method for IMRT QA Film Dosimetry Using Gafchromic® EBT Film

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Purpose: In order to decrease the workload for IMRT QA film dosimetry we propose a simple method for Gafchromic® EBT film calibration using a pre-measured batch calibration curve (BCC) which is mathematically scaled with a single dose exposure (SDE) for each subsequent IMRT QA session. We evaluate how the SDE method corrects for post exposure density growth and temperature dependence in addition to inter film response homogeneity. **Method and Materials:** Each of five EBT films, from a single production lot, were exposed to doses of 22.5, 43.1, 84.4, 147.4, 209.1, and 291.2 cGy. Measurement of the resulting response curves were performed at times ranging from 0.7 to 52 hours post exposure on a Macbeth TD932 point densitometer customized with a 636nm band pass filter and 16 bit digitizer for increased sensitivity, yielding 35 curves in all. The BCC was generated from a film measured at 0.7 hours and fit to the equation $Dose = A*netOD^3 + B*netOD^2 + C*netOD$. To test the method, net optical density (NOD) data for the remaining 34 curves was scaled to fit the BCC using 209.1 cGy as the SDE. The scaling factor is the ratio of the actual measured NOD of the SDE, and the NOD predicted by the BCC for this dose. The new scaled calibration is used to predict all 204 test doses, which were then compared to the actual delivered doses. **Results:** Using the single uncorrected BCC resulted in an average error for the 204 dose points of 11.9 cGy. However, scaling according the method described reduced the average measured dose error to 1.1 cGy. **Conclusion:** The single dose exposure method described here is an accurate and time efficient calibration procedure for IMRT QA film dosimetry. **Conflict of Interest:** Partially supported by International Specialty Products.

Exhibit Hall F

General Poster Discussion
Professional

SU-FF-P-01

Management Issues in Implementing IGRT

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Purpose: To investigate and develop an appropriate framework for establishing and monitoring staff competency for IGRT procedures in the community setting. To evaluate existing resources to establish and monitor staff competency. **Method and Materials:** The full benefit of IGRT can only be realized through the proper deployment of appropriate technology coupled with staff expertise in technical and clinical aspects of IGRT. All of the three main technical processes comprising the treatment chain in IGRT: CT simulation, treatment planning and delivery are greatly increased in complexity compared to 3D CRT. This necessitates the acquisition and monitoring of additional competencies among staff in their technical and clinical skill sets. Management is faced with the challenges of 1. providing competency training for staff and monitoring performance, 2. developing and implementing appropriate policies, procedures and oversight, to ensure the accuracy of IGRT treatments. Anecdotal evidence suggests an accelerating pace of IGRT technology diffusion among community radiation therapy centers. However, there seem to be inadequate formal resources for staff training and competency certification in IGRT procedures, which can hinder the optimal use of the technology in the community setting. In this work, existing frameworks for staff and quality management are examined along with a review of available resources. Experiences of a medium sized community hospital in implementing IGRT are discussed.

SU-FF-P-02

Live Webcast and Video Archiving of Physics Seminars

M Woo*, Toronto Sunnybrook Regional Cancer Ctr, Toronto, ON, CA

This presentation is to report and promote a webcasting and video archiving project at our cancer centre. We use a commercial system that requires special hardware to be installed in the presentation room, although a portable system is also available to videotape lectures but not for live webcast. The process begins with an email to the invited speaker, explaining the process and requesting his or her permission for the videotaping. Once the speaker agrees to it, the hospital's IS department is notified. All that is required of the IS staff is to enter the basic information on their computer, and then, at the actual time of the seminar, observe the speaker remotely on their TV monitor and adjust the video camera. The speaker image, the audio, together with the screen image of the speaker's presentation computer, will then be broadcast live on the web. To view the broadcast, intended audience will be sent a link in advance. The same link can be used to view the archived seminar afterwards. The archiving is done automatically, with no extra step for the IS staff. For the live webcast, some electronic form of remote audience participation, such as polling and sending questions by email, is available. We have decided that a speaker phone for audience to phone in would be most effective. The whole process is extremely easy to implement and also transparent to speakers, and the feedback has been highly positive. We are in the process of setting up an announcement for upcoming talks, as well as a catalog of archived talks. We encourage the Medical Physics community to participate in the project as audience. We would also like to promote this concept for other centres to set up similar facilities so that information and knowledge could be shared widely.

SU-FF-P-03

Combined Role Of Physicist And Technologist In Optimizing CR, DR Techniques To Meet The Regulations And ALARA!

N Venkataramanan*, V Koehler, D Gregorius, Winthrop Univ Hospital, Mineola, NY

With advancement of CR and DR, many facilities are switching from regular FILM-Screen combination to these new technologies. While manufacturers suggest basic techniques for different projections to be used in the radiography rooms, it is our experience, to notice that, some of the prescriptions may not meet the need. Adjusting to a different technique may make the entrance skin exposures for different projections exceed the regulatory limits. It is the responsibility of the Medical Physicist to make sure that ALARA is met in these situations while making sure that image quality is not compromised. Role of the technologist is very important to optimize the exposures. This paper will discuss the failure part and the necessary problem solving steps. Tables for entrance exposures for Film-screen, CR and DR will be discussed with optimum techniques used in our institution as a model.

SU-FF-P-04

New Stereotactic Radiosurgery CPT Codes for 2006

J Hevezi*, South Texas Oncology & Hematology, San Antonio, TX

New Stereotactic Radiosurgery CPT Codes for 2006

Purpose: To identify the new planning codes for stereotactic radiosurgery (SRS) and stereotactic body radiation therapy (SBRT) beginning January 1, 2006. **Methods & Materials:** On Jan. 1, 2006, CMS promulgated new procedure codes for SRS and SBRT planning. Previously, G0338 was to be used to cover this work in the hospital setting for Medicare patients. After this date, the CPT radiation therapy planning codes available in the 77XXX series are to be used to cover the work of SRS and SBRT planning. **Results:** The CPT code for 3D planning, CPT 77295 will now be used to cover the work previously covered under the temporary G0338 code in the hospital setting. All of the applicable CPT codes that cover additional work for a course of radiation therapy (77300, 77336, 77370, 77470, etc) will still be available to cover work associated with the treatment course. The new stereoscopic guidance code, 77421, is however bundled into the G codes used for delivery, at present. Suggested codes will be presented. **Conclusions:** SRS and SBRT users will need to use CPT codes to cover

the work of planning for these procedures after Jan 1, 2006**.** Other carriers will likely follow CMS' recommendation, but they should be queried for their policy on this coverage, lest denial of payments ensue.

SU-FF-P-05

Medical Physics Situation in Colombia

N Machado[1], M Plazas*[2], (1) National Cancer Institute, (2) Universidad Nacional de Colombia, Santafe de Bogota, CO

Purpose: To describe the current situation of the Medical Physics field in Colombia concerning to human resources, physics infrastructure (radiation oncology centers, radiation machines, treatment planning systems, dosimetry systems, nuclear medicine and diagnostic facilities, imaging devices and radiation protection systems), academic programs, medical physics societies and regulatory institutions**. Method and Materials:** For this presentation we have taken as reference some studies carried out in Colombia during the last few years as follows**:**

- Evaluation of radiation oncology facilities in Colombia, an audit study conducted to evaluate the radiotherapy centers and the quality of assistance for cancer patients**.**

Comparison among Medical Physics academic programs offered in the world, specially those carried out in the Latino-American region**. Results:** Up to the date the mentioned study was conducted, there was 46 radiation therapy centers in Colombia and only 14 had medical physicists.

The number of nuclear medicine centers existing in Colombia was approximately 47, mainly concentrated in Bogotá, where 22 of them are located**.** Currently the number of medical physicists working in the nuclear medicine facilities in Colombia is really scarce.

Worldwide it can be seen that North America is the region with the greatest number of universities offering Medical Physics Master programs**.** In the Latin American context, Mexico had the greatest number**.**

The statistical distribution of diagnostic x ray machines was about 53000 in Latin-American countries and the number of medical physicist working to these centers is very low.There is human resources shortage, especially for Medical Physicists in the radiation oncology, nuclear medicine and diagnostic facilities. There are some academic programs in Medical Physics**.** Currently there is a increasing interest from universities in Colombia to create medical physics under and postgraduate programs.

MONDAY, JULY 31

Imaging Continuing Education Course — Room 330 A

CE: Breast Imaging Physics and Technology - I

MO-A-330A-01

Recent Advances in Digital Mammography

M Yaffe*, Sunnybrook Health Sciences Centre Research Inst, Univ Toronto, Toronto, ON, CA

Digital mammography was developed to address several technical limitations of screen film mammography with the goal of improving the accuracy of detecting breast cancer. The recent publication of the results of the ACRIN DMIST study has demonstrated such an improvement in a subset of women, notably , younger women and those with dense breasts. Nevertheless, the study also indicated that a significant fraction of cancers were not detected by either film or digital mammography. This is likely due to a number of reasons including the biology of the cancers, inadequate conspicuity of the lesions and variability of the skills of the radiologists. While it probably is not possible to detect all these cancers with mammography there are promising new techniques that can be developed on the platform of digital mammography to improve detection. One of these is computer-aided detection, the use of computer artificial intelligence algorithms to identify patterns in the digital images that are suspicious for the presence of cancer. These provide some of the advantages of double reading of the mammograms (interpretation by two different radiologists), a process known to improve the sensitivity of cancer detection. Another new technique is contrast-enhanced digital mammography (CEDM), which images leakage of an iodine contrast agent from microscopic vessels formed in the vicinity of a growing tumour. By imaging this tumour angiogenesis, cancers that are invisible on mammography might be seen. In addition, better information about the extent of the disease will be helpful in planning therapy. In mammography all of the anatomy in the 3-dimensional breast is superimposed in two dimensions to form the image. Tomosynthesis and breast CT provide three-dimensional images to separate the structures within the breast, possibly allowing tumors to be seen more easily and eliminating the overlap of structures from different parts of the breast that can falsely resemble a cancer. Telemammography can help improve the accessibility of high quality mammography in sparsely-populated communities. In this presentation, the current status and the potential of these exciting new techniques will be considered.

Disclosure:
Martin Yaffe's laboratory carries out research on topics related to digital mammography in collaboration with GE Healthcare. Martin Yaffe is a member of the Scientific Advisory Board of XCounter.

Educational Objectives:
1. Become familiar with current challenges in breast cancer imaging
2. Learn about new techniques that are available or under development to address these challenges

Imaging Continuing Education Course — Room 330 D

CE: PET Physics and Technology - I

MO-A-330D-01

Advances in PET Technology - New Crystals and Detector Designs

F Fahey*, Children's Hospital, Boston, MA

Over the past ten years, the use of clinical PET, particularly in the field of oncology, has increased dramatically. More recently, the introduction of hybrid PET/CT scanners has led to an enhanced ability to provide anatomical correlation to the functional findings on the PET scan. And lastly, the growing field of molecular imaging has led to the development of a variety of dedicated PET systems for small animal imaging. In the clinical arena, the goal is to develop scanners with higher sensitivity and count rate capability to be able to acquire whole body scans more efficiently. Efficiency is essential with respect to small animal imaging as well, but it must be accomplished with very high spatial resolution. This presentation will review the basics of PET imaging with a look towards the advances being made to address the needs of these two very different imaging tasks. The use of 2D versus 3D will be discussed as well as the effect using different crystal materials. Other advances being actively pursued such as the use of time-of-flight PET will also be discussed.

Educational Objectives:
After attending this presentation, the attendee will be able to list 2 advantages and 2 disadvantages of 3D PET compared to 2D PET for clinical, whole body imaging, name 3 different materials used in state-of-the-art PET scanners and list 2 advantages of each, and discuss two potential advantages for time-of-flight PET.

Imaging Continuing Education Course — Valencia A

CE: Medical Imaging Informatics - I

MO-A-ValA-01

The Role of the Physicist in the Planning and Design of Digital Image Management Systems (PACS)

S Langer*, Mayo Clinic, Rochester, MN

The classically trained medical physicist strives to yield maximum diagnostic information from an exam with minimal impact on patient health (i.e. by minimizing dose). This simple objective means that in practice the physicist must: become expert on following the latest technological developments across modalities to assist in equipment purchases, monitor and oversee the imaging protocols used at an institution, and monitor the equipment performance over its lifetime.

As the department transitions to filmless radiology, the mission remains the same, but the scope of implementation increases. The DICOM services that an imager supports are analogous to the filming options supported of yesteryear. The H&D curve of film days maps to the DQE and JND of today's detectors and displays. Quality Control encompasses not only median film density of a laser camera and MTF of a CT, but how those image properties propagate from acquisition to final display device. The key point to realize is the medical physicist is uniquely empowered to have a holistic systems view of the imagers, PACS, RIS and the needs to QC the entire chain.

In this lecture, we will discuss the value add that the medical physicist provides due to the unique collection of training and skills we possess.

Educational Objectives:
1. Compare and contrast the classic role of a medical physicist in the film based department verses the filmless radiology department
2. Identify the areas of technology and practice where the Medical Physicist adds value
3. Case studies of cost savings made possible by the practice knowledge that a medical physicist brings to the table that IT staff may not have

Imaging Continuing Education Course — Valencia B

CE: Computed Tomography Physics and Technology - I

MO-A-ValB-01

Tradeoffs in Image Quality and Radiation Dose for CT

M McNitt-Gray*, David Geffen School of Medicine at UCLA, Los Angeles, CA

In CT scanning, image quality has many components and is influenced by many technical parameters. While image quality has always been a concern for the physics community, clinically acceptable image quality has become even more of an issue as strategies to reduce radiation dose – to all patients, but especially to pediatric patients– has become a focus in many radiology practices.

The purpose of this presentation will be to first describe several of the components of CT image quality – noise, slice thickness (Z-axis resolution), low contrast resolution and high contrast resolution– as well as radiation dose and to describe how each of these may be affected by technical parameter selection. This presentation will pay particular attention to the tradeoffs that exist between different aspects of image quality, especially when the reduction of radiation dose is one of the objectives.

The presentation will then explore several mechanisms that can be used to reduce radiation dose in CT exams and the implications for the diagnostic image quality of the exam. Specifically, the implications of varying the tube current*time product (mAs), pitch or tablespeed (or for axial imaging, the table increment), slice thickness, beam energy (kVp), patient (or phantom) size and dose reduction options (such as tube current modulation) will be described for both radiation dose and diagnostic image quality. Finally, this presentation will emphasize that the tradeoffs between radiation dose and image quality are clinical-task dependent; that is, the goals of the clinically indicated exam dictate what aspect of image quality may be emphasized for that exam (low contrast resolution or high contrast spatial resolution, etc.) and this will have implications for the amount of radiation dose reduction that is acceptable. This will be illustrated with examples from selected diagnostic imaging exams.

Educational Objectives:
1. Understand key components of image quality in CT scanning as well as reinforce CT radiation dose concepts.
2. Understand the impact that technical parameter selection has on the various aspects of image quality and radiation dose.
3. Examine the tradeoffs between various aspects of image quality and radiation dose.
4. Examine the impact of these tradeoffs on a few clinical imaging protocols and illustrate the task-dependence of image quality requirements.

Therapy Continuing Education Course — Room 224A

CE: Treatment Planning Optimization Parameters

MO-A-224A-01

Treatment Planning Optimization Parameters - MD

L Marks* , Department of Radiation Oncology , Duke University Medical Center
Durham, NC

Three-dimensional radiation therapy (RT) planning tools provide detailed information regarding the degree of radiation exposure to different volumes of organs. Presently, we have incomplete knowledge regarding the tolerance doses for different normal tissue organs. The classic "Emami paper" (IJROBP 1991) provided broad dose/volume guidelines for 3D RT planning, based on somewhat limited clinical data. More recently, there has been dramatic increase in the number and quality of clinical studies that attempt to relate dose/volume parameters to normal tissue risks. Presently, dosimetric parameters predictive for injury are available for several organs (e.g. the lung, heart, esophagus, parotid, and brain), and additional/better data is rapidly accumulating. However, for most organs, the presently-available predictive models are suboptimal. The continued challenges include: non-uniform definitions of toxicity (e.g. radiologic vs. analytic vs. symptomatic), clinical comorbidities that make the diagnosis of RT-induced toxicity uncertain, the confounding effects of concurrent chemotherapy (that is being used with increasing frequency), and multi-organ nature of some clinical endpoints. Further, it is not clear if the dose/volume guidelines developed in the "3D era" are applicable in the hypofractionated/radiosurgery/IMRT era. Extreme caution is warranted to the extrapolation of dose/volume guidelines beyond the scope within which they were defined. For example, the variable fraction size delivered to the surrounding normal tissues with IMRT/radiosurgery is fundamentally different than the relatively-uniform fraction sizes received by the normal tissues in the 3D era. Since most normal tissue effects are very sensitive to fraction size, this variable needs to be considered. IMRT actually makes the decision-making process more complex for the physician, as we now have greater flexibility regarding where to deposit the "extraneous/incidental" RT dose. Thus, the need for better dose/volume guidelines, that include consideration of fraction size, has increased with IMRT. When normal tissue dose/volume data becomes more robust, we will be better able to exploit the full potential of 3D/IMRT to minimize radiation-induced normal tissue injury.

Therapy Continuing Education Course — Room 24C

CE: Daily Localization - I: Kilovolt Imaging

MO-A-224C-01

Daily Localization I: KV/CBCT

F Yin*, S Yoo, Z Wang, D Godfrey, Q Wu, Duke University Medical Center, Durham, NC

Daily target localization is a critical step to secure accurate delivery for 3-D conformal radiation therapy and intensity-modulated radiation therapy. One emerging technology using in-room kilovoltage (kV) imaging has shown to be very promising for targeting treatment volumes. The major advantages of using kV imaging are 1) its comparable contrast between soft tissue and bone structure to that in simulation images, 2) real-time high resolution fluoroscopic imaging, 3) lower radiation dose to patient compared to conventional MV imaging, and 4) availability of reconstructing tomographic images (for example, cone-beam CT) using 2-D kV projection images. At present, different types of in-room kV imaging systems are being developed for different applications such as in-room CT on rail, ceiling-mounted dual-source/detector configuration, and gantry-mounted single source/detector system. In terms of clinical applications, some generate 2-D radiographic images for target verification based on bony marks or implanted surrogator while others generate 3-D tomographic images for target verification based on both soft tissues and bony structures. Some could be used for viewing organ motion to verify applied margin while others could be used for monitoring target motion to verify dynamic delivering or gated treatment. Issues related to the risk and benefit between imaging information and radiation dose using 2-D or 3-D imaging, the geometric accuracy of imaging systems, trade-off between treatment accuracy vs. time required to carry on imaging and manipulation process, early image-guided protocols for basic clinical applications, etc. will be discussed. Some new developments related to effective and efficient use of in-room kV and MV imaging, tomographic image reconstruction using limited number and angle projections have shown very promising for future clinical applications.

This lecture will describe the commercially avaialbe kV imaging systems, as we as their applicable clinical protocols, acceptance testing and commissioning processes, basic QA requirements, system limitations, and potential future developments.

Educational Objectives:
1. Understand the latest commercial available technologies for in-room kV and CBCT systems
2. Understand the basic functionalities of in-room kV imaging system
3. Understand the basic imaging applications
4. Understand the basic system limitations and QA

Therapy Continuing Education Course — Room 230A

CE: Monte Carlo - I: Machine and Source Modeling

MO-A-230A-01

Monte Carlo I: Source Modeling and Beam Commissioning for Treatment Planning

C Ma*, Fox Chase Cancer Center, Philadelphia, PA

In this presentation, we will discuss source modeling and beam commissioning for Monte Carlo treatment planning. We will review the current status of Monte Carlo simulations of clinical photon and electron beams and the theories and methodologies used in particle phase space representation and reconstruction for Monte Carlo dose calculation. We

will discuss the sensitivity of beam characterization to simulation details, such as beam energy, angle, intensity, and details of the treatment head design. We will review different source models for photon and electron beam characterization and discuss the accuracy and efficiency tradeoffs between full phase space and simplified source models. We will describe the methods and software that have been developed for source modeling and beam commissioning for the clinical implementation of the Monte Carlo method for treatment planning and beam delivery verification. We will present different methods for source parameterization based on simulated phase space data and a standard set of measured beam data including in-air and in-phantom output factors and in-phantom dose distributions.

Educational Objectives:
1. Describe the Monte Carlo method for clinical photon and electron beam simulations
2. Review theories and methodologies for phase space representation and reconstruction
3. Present different source models for Monte Carlo dose calculation
4. Describe different methods for source parameterization and beam commissioning

Imaging Continuing Education Room 330 A Course
CE: Radiation Safety and Risk Management - I

MO-B-330A-01
Patient Radiation Doses in Diagnostic Imaging
E Nickoloff*, Z Lu, Columbia Univ, New York, NY, Columbia University Medical Center, New York, NY

The main goal of this presentation is to discuss factors which affect patient radiation dose delivered during various diagnostic radiology imaging examinations and to relate these radiation doses to potential biological risks. Measurement methods to estimate patient radiation doses and some examples of dose reduction for radiography, mammography, fluoroscopy, angiography and CT will be reviewed. Applications of these measurements to patient dose estimation will be shown. Procedures to obtain quick computational estimates of patient doses for IRB submissions, patient inquiries and fetal dose estimations will be provided. Approaches to convert entrance skin doses, dose area products and dose length products to effective doses and risks will be discussed. Typical patient radiation dose values for common diagnostic imaging procedures will be given. Limitations, uncertainties and ranges for patient radiation dose estimates will be examined. The utilization of "reference values" for patient radiation doses will be reviewed. Some guidelines to aid physicists with relating radiation dose issues to the public and informational media will also be included. The material is intended to provide a brief overview of one crucial aspect of the responsibilities with which diagnostic medical physicists and medical health physicists must routinely handle in their jobs. Our expectation is to stimulate introspective assessments and to expand the manner in which patient radiation dose determinations are viewed and performed.

Educational Objectives:
1. To review fundamental X-ray dosimetry quantities.
2. To identify important factors that affect patient dose delivered by various X-ray imaging modalities.
3. To describe common methods to measure patient dose and review strategies in developing patient dose charts for routine diagnostic imaging procedures.
4. To examine the limitations of some current dosimetry methodologies.
5. To present a practical guidance to physicists in providing day-to-day clinical support service such as IRB submissions, patient inquiries and fetal dose estimations.

Imaging Continuing Education Room 330 D Course
CE: Radiography Physics and Technology - I

MO-B-330D-01
Design and Performance Characteristics of Computed Radiographic Acquisition Technologies
R Schaetzing*, Agfa Corporation, Greenville, SC

Digital Radiography (DR) using Storage Phosphors, also known as Computed Radiography (or CR), has been commercially available for a quarter of a century. Each new generation of scanners and screens has brought improvements in image quality, throughput, physical size and cost. With these improvements has come a high level of clinical acceptance, with a corresponding displacement of screen/film systems as the standard for projection radiography acquisition.

Scanner improvements include better, more reliable light sources, more efficient light collection systems, higher quality photodetectors, and better electronics. The latest CR scanner advances have done away with traditional flying-spot (point-at-a-time) scanning in favor of line-at-a-time scanning, bringing significant throughput, image quality, and size advantages. At the same time, advances in the design and manufacture of powder-based, particle-in-a-binder CR screens, or image plates, have enabled improved inherent signal and noise properties (x-ray absorption, Modulation Transfer Function, Noise Power Spectra, Detective Quantum Efficiency, etc.), and a better matching of screen absorption and emission spectra to the scanner characteristics. Screens with transparent substrates have produced improved image quality due to the ability to extract latent image signal from both sides of the screen. The latest storage-phosphor screen materials can be grown in needle form, similar to the scintillators used in indirect flat-panel detectors, resulting in dramatically improved image sharpness and higher x-ray absorption due to the absence of binding material.

This presentation will review the form, function and performance of CR systems, with an eye towards more recent developments. The current state of the art in CR will be placed into the larger context of newer DR acquisition systems (e.g., active-matrix flat panels), looking at the advantages and disadvantages of each. Advances made in CR technologies in recent years portend continued expansion of CR-based medical imaging.

Educational Objectives:
1. Describe the form and function of today's computed radiography (CR) systems
2. Identify the main factors that influence the image quality of CR systems
3. Compare modern CR systems to other acquisition technologies
4. Describe the latest and future developments in CR

Conflict of Interest Statement
The author is employed by Agfa Corporation.

Imaging Continuing Education Course Valencia A
CE: Fluoroscopy Physics and Technology - I

MO-B-ValA-01
Modern Fluoroscopic Equipment Design - What's Different with Flat Panel?
J Rowlands,*Sunnybrook & Women's College, Toronto, CA

(No abstract provided)

Imaging Continuing Education Course Valencia B
CE: MRI Physics and Technology - I

MO-B-ValB-01
Advances in MRI Equipment Design, Software, and Imaging Procedures
M Steckner*, Hitachi Medical Systems America, Inc., Twinsburg, OH

The advances in MRI technology are relentless. Virtually every aspect of MR scanners is being modified and optimized. There are a myriad number

of factors that drive these advances. Clinical requirements are the most obvious and important driver, but are significantly influenced by the clinical setting and/or business model. Is the scanner for a large hospital radiology department, or dedicated interventional procedures scanner, or for an orthopedic, cardiac, pediatric or breast practice or a walk-in radiological clinic? Each of these market segments places a different relative importance on the various MR system performance specifications. Consequently, the commercially available MR scanners have their own unique operating characteristics as the various MRI vendors seek to satisfy their customers' needs. This lecture will examine some of the various sub-systems and discuss selected development trends, such as:

1) Utilization of novel spatial encoding mechanisms to accelerate image acquisition: parallel imaging and the coil spatial response mechanism.
2) Magnet field strength is increasing and physical magnet size is changing: shorter magnets and larger apertures.
3) Increase the effective imaging volume with advances in moving couch methods: the couch becomes another spatial encoding mechanism.
4) Demands on the reconstruction engine are constantly growing: commercial consumer electronic technology advances help provide cost effective, faster solutions.
5) Parallel receive concepts are adapted to the transmit side: transmit-SENSE. It is not commercially available, yet.
6) More than pretty pictures: numbers. The growth in quantitative MRI and CAD.

While these technology advances are increasing system complexity, flexibility, sequence capabilities, image quality, throughput efficiencies etc, associated technology advances are also mitigating the package footprint and costs.

Educational Objectives:
1. Recognizing the advances in MRI
2. Understand the technology underlying these advances
3. Understand the scientific/medical reasons for these advances
4. Recognize that the commercial implementations are targeted at specific customer segments/requirements.

Conflict of Interest: The author is employed by Hitachi Medical Systems America, Inc.

Therapy Continuing Education Course — Room224 A

CE: Sheilding I: New NCRP Report: General Report background and formulation

MO-B-224A-01

Shielding I: New NCRP Report: General Report Background and Formulation

J Deye*, National Cancer Institute, Bethesda, MD

This Report was prepared through a joint effort of the AAPM Task Group 57 and the NCRP Scientific Committee 46-13. It addresses the structural shielding design and evaluation for medical use of megavoltage x rays and gamma rays for radiotherapy and supersedes related material in NCRP Report No. 49, which was issued in 1976.

This first presentation will review the general formalisms used for primary and secondary barrier designs at energies below and above the 10MeV maximum energy that was considered by the old Report 49. While most of the formalisms and data can be found in the published literature, the goal of the report was to bring together in one work all the required methods for shielding modern radiotherapy accelerators. This overview will be followed on the second day by a review of the methods and equipment that are necessary to survey the final facility and then the equations and data presented will be used extensively in the third day's presentation to work a number of detailed example calculations.

Learning Objectives:
1. Understand the history and rationale behind this report,
2. Understand the appropriate use of the equations and data for calculating shielding for medical accelerators,
3. Understand the limitations of the proposed methods.

Therapy Continuing Education Course — Room 224 C

CE: Action Levels for IMRT QA

MO-B-224C-01

Action Levels for IMRT QA

J Palta*, S Kim, Univ Florida, Gainesville, FL

Each intensity-modulated radiation therapy (IMRT) field includes many small, irregular, and asymmetric fields that completely obscure the relationship between monitor unit (MU) setting and radiation dose. Uncertainty and inaccuracy of dose delivery with IMRT is primarily attributed to the leaf positioning accuracy, modeling of radiation output for small field sizes, modeling of beam penumbra, and the dose outside the IMRT field. Dose-difference distribution, distance-to-agreement (DTA), and a numerical gamma index are often used to evaluate the quality of agreement between measured and calculated dose distributions for the IMRT fields. The tolerance limits based on these indices for IMRT QA are often not adequate because all these methodologies do not account for space-specific dose uncertainty information. In other words, single tolerance criterion is applied to all test points even when dose uncertainty is significantly different from point to point. At any given point, the dose uncertainty depends on different levels of dose and gradients from multiple small beams rather than that of the overall dose
profile. Therefore, new methodologies are needed that determine dose uncertainties based on the dose level and gradient information of each small field. In IMRT, it is sometimes difficult to have agreement between calculation and measurement of dose at all points in a 3-D dose distribution. A disagreement at a few points does not necessarily lead to negative overall result if other comparable points are
well within the established tolerance limits. We will describe a new approach in establishing tolerance limits and action levels for IMRT QA that will ensure delivery of prescribed radiation dose within an acceptable limit of 5%.

Educational Objectives:
1. To describe the uncertainties in IMRT planning and delivery
2. To describe the impact of spatial and dosimetric uncertainties on the IMRT dose distribution
3. To describe the limitations of current methodologies of establishing tolerance limits for IMRT QA
4. To describe new methodologies for establishing tolerance limits for IMRT QA

Therapy Continuing Education Course — Room 230A

CE: TG-43 Update

MO-B-230A-01

AAPM TG-43 Update for 2004 and Beyond

MJ Rivard*[1], WM Butler[2], LA DeWerd[3], MS Huq[4], GS Ibbott[5], CS Melhus[1], MG Mitch[6], R Nath[7], JF Williamson[8], (1) Tufts-New England Medical Center, Boston, MA, (2) Wheeling Hospital, Wheeling, WV, (3) University of Wisconsin, Madison, WI, (4) UPMC Cancer Center, Pittsburgh, PA, (5) UT M.D. Anderson Cancer Center, Houston, TX, (6) Nat'l Institute of Standards & Technol, Gaithersburg, MD, (7) Yale Univ School of Medicine, New Haven, CT, (8) Virginia Commonwealth University, Richmond, VA

Since publication of the 2004 update to the American Association of Physicists in Medicine (AAPM) Task Group No. 43 Report (AAPM TG-43U1), several new low-energy photon-emitting brachytherapy sources have become available. Many of these sources have satisfied the AAPM prerequisites for routine clinical use as of January 10th, 2005, and are posted on the Joint AAPM/RPC Brachytherapy Seed Registry. Consequently, the AAPM has prepared this supplement to the 2004 AAPM

TG-43 update. This paper presents the AAPM-approved consensus datasets for these sources, and includes the following ^{125}I sources: Amersham model 6733, Draximage model LS-1, Implant Sciences model 3500, IBt model 1251L, IsoAid model IAI-125A, Mentor model SL-125/SH-125, and SourceTech Medical model STM1251. The Best Medical model 2335 ^{103}Pd source is also included. While the methodology used to determine these datasets is identical to that published in the AAPM TG-43U1 report, additional information and discussion are presented here on some questions that arose since the publication of the TG-43U1 report. Specifically details of interpolation and extrapolation methods are described further. Despite these small changes, additions, and clarifications, the overall methodology, the procedures for developing consensus datasets and the dose calculation formalism remain the same as in the TG-43U1 report. Thus, the AAPM recommends that the consensus datasets and resultant source-specific dose-rate distributions included in this supplement be adopted by all end users for clinical treatment planning of low-energy photon-emitting brachytherapy sources. Adoption of these recommendations may result in changes to patient dose calculations, and these changes should be carefully evaluated and reviewed with the radiation oncologist prior to implementation of the current protocol.

Joint Imaging/Therapy Symposium — Valencia A

President's Symposium: Regulations, Regulations, Regulations!

MO-C-ValA -03

Commissioner Jaczko's Perspective on the Use of Byproduct Material in Medicine

Commissioner G Jaczko*, U.S. Nuclear Regulatory Commission, Washington, DC

(No abstract provided)

MO-C-ValA -04

FDA

Acting Commissioner A von Eschenbach*, National Cancer Institute, Bethesda, MD

(No abstract provided)

Imaging Scientific Session — Room 330 A

Computed Tomography

MO-D-330A-01

Retrospective Sorting of 4D CT Into Breathing Phases Based On Imaging Analysis of a Fixed-Geometry Fiducial

J Hoisak*[1], M Kaus[1, 2], T Purdie[1], D Jaffray[1], (1) Princess Margaret Hospital, Toronto, Ontario, CA (2) Philips Research USA, Briarcliff Manor, NY

Purpose: To evaluate a novel fiducial method for retrospective sorting of four-dimensional computed tomography (4D-CT). Breathing-induced motion and deformation of internal anatomy confounds planning and delivery of radiotherapy. Patient-specific assessment of respiratory motion using 4D-CT is becoming more clinically accepted as it depicts discrete sampling of the internal anatomy throughout the respiratory cycle. Various strategies for sorting the images exist. External strategies rely on integration of a motion sensor with the CT device but may lack robustness with respect to sensor location. Internal strategies based on image analysis alone may not be robust enough. This work proposes a hybrid retrospective sorting method based on an easily positioned fiducial device that does not require additional hardware and is usable with any multi-slice or helical CT scanner. An image-processing algorithm automatically extracts the breathing phase of each slice by fiducial position and sorts images into phases accordingly. **Method and Materials:** A 50 cm rod-like device covering the entire field-of-view is placed along the patient, providing a well distinguishable fiducial position in each CT slice without impacting image quality. Image analysis determines the fiducial centroid position in each slice with sub-mm accuracy, allowing phase-based binning of the image slices according to breathing phase. To validate the method, a motion phantom with the rod affixed was subject to a cine 8-slice CT scan with 2.5 mm slice thickness. Images were sorted with the fiducial method and compared with images sorted by a commercial 4D-CT system. **Results:** Phase-sorted images of the phantom were reconstructed using the fiducial method. Image quality was comparable to those reconstructed by the commercial 4D-CT system. **Conclusions:** Image analysis of a rod fiducial allows retrospective sorting of 4D CT according to breathing phase. This method does not require additional hardware, interfacing with the CT scanner, or manual interaction with the images.

MO-D-330A-02

Motion Artifact Correction Using a Novel Data Consistency Condition

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Purpose: During diagnostic x-ray CT imaging procedures or image guided radiotherapy, image quality will be degraded if target organs move during the data acquisition. This can be caused by patients' occasional motion or by intrinsic motion like cardiac and respiratory motion. The inconsistency in the projection data is the major reason for the image quality degradation. We present and validate a method to improve the consistency of the projections using a novel Fan-beam Data Consistency Condition (FDCC) such that the image quality can be improved. **Method and Materials:** Computer-simulated dynamic phantoms are generated and projection data are acquired from these dynamic phantoms. Using the FDCC, individual projection data from one view of fan-beam projections can be estimated from filtering all the other projection data acquired from different view angles. Then those projections contaminated by motion are re-estimated using the FDCC, resulting in a corrected sinogram. A standard Fan-beam Filtered Back Projection (FBP) reconstruction algorithm is then used to reconstruct images from the corrected sinograms. Motion artifacts can be alleviated using this procedure. **Results:** Images are reconstructed from both the original sinogram where projections are contaminated by motion and the corrected sinogram after applying the FDCC. Strong motion artifacts are observed in the images reconstructed from the contaminated sinogram while improvement can be found in the reconstructed images using the corrected sinogram. **Conclusions:** A novel method using the new FDCC is proposed to combat the motion artifacts due to the temporal inconsistency in the projection data. Numerical simulations were conducted to demonstrate the potential of this correction scheme to mitigate motion artifacts. Thus, the preliminary numerical results indicate that the FDCC has potential use in combating both cardiac and respiratory motion in CT imaging.

MO-D-330A-03

Correction of Streaking Artifacts in CT Images and Its Influence On Monte Carlo Dose Calculations

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Purpose: To quantify the impact of streaking artifacts in CT images due to metal implants in patients on Monte Carlo dose calculation and to determine the impact of their correction. **Method and Materials:** For CT artifact correction a method of interpolation of missing data in sinograms was developed. Three contrast phantoms were constructed containing two steel cylinders that produced streaking artifacts. CT scans of the phantoms were obtained and the images were corrected for the artifacts. Three sets of Monte Carlo dose calculations (MCDC) using EGSnrc/DOSXYZnrc code were performed. Dose was calculated on: (1) the original CT image, (2) the CT artifact corrected image, and (3), the exact phantom geometry. The dose distributions of the original CT images and the CT artifact corrected images were then compared to the dose calculated on the exact geometry. **Results:** A calibration point for metal had to be added to the default EGSnrc CT calibration curve to improve dose calculation results. Additional improvement in dose calculation results and in image quality was noted after the artifact correction was done. MCDC without adding the extra calibration point and without correction for streaking artifacts was found to lead to large dose errors. The error in dose calculations performed with the default calibration was found to be 25% in the original CT images. The error improved greatly when the CT images were corrected for artifacts and when the extended calibration was used; the error decreased then to less than 2 %. **Conclusion:** This work proves that the correction of streaking artifacts is important for MCDC; it significantly decreases dose calculation error and it improves image quality. The work also suggests

that for MCTP an additional calibration point for a metallic material should be added to the default CT calibration curve.

MO-D-330A-04

Exploitation of Data Redundancy in a Reduced Fan-Beam Scan

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Purpose**:** We aim to devise new weighting schemes to improve the signal-to-noise ratio (SNR) in images reconstructed from data acquired in reduced fan-beam scans by fully utilizing the redundant information**. Method and Materials:** Recently, we have developed a backprojection-filtration (BPF) algorithm, which can reconstruct ROI-images from the transversely truncated data in a reduced-scan with a scanning angular range less than that in a short-scan**.** However, the measured data in a practical reduced scan contain some redundant information**.** In this work, we devised two weighting schemes to appropriately incorporate the redundant data**.** Applying the weighting schemes to the BPF algorithm, we derived two new algorithms, derivative of weighted BPF (WD-BPF) and weighted-derivative BPF (DW-BPF) algorithms**.** Both of these two algorithms can be used to improve the SNR in reconstructed images**. Results:** The ROI-images are reconstructed from the truncated projection data in a short-scan and a reduced-scan, respectively**.** For the reduced-scan, some shading artifacts appear in the images reconstructed by use of the WD-BPF algorithm**.** This is caused by the numerical error in the derivative of the discontinuous weighting function**.** In contrast, artifact-free images can be obtained by use of the DW-BPF algorithm**.** For the short-scan, both algorithms can obtain artifact-free images, because the weighting function is smooth**.** The results in the noise study show that image noise obtained by use of WD-BPF and DW-BPF algorithms are similar within the ROI**. Conclusion:** We propose two weighting schemes for handling the data redundancy in reduced-scan fan-beam CT**.** Our results demonstrate that the proposed two algorithms can utilize the redundant data to improve the signal-noise ratio**.** Moreover, the noise properties of these two algorithms are similar to each other.

MO-D-330A-05

Cone-Helical CT Imaging Using the 256-Row (Cone Beam) CT Scanner

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We evaluated Feldkamp artifacts, which are specific to cone-beam CT, in phantom and clinical studies using the 256 multi-detector-row CT (256MDCT), and compared the reconstruction accuracy of axial and helical scans.

Image noise, slice sensitivity profile (SSP) and artifacts with the 256MDCT were evaluated using a phantom and the results were compared to those with a 64MDCT**.** We also examined chest and abdomen scans produced with the 256MDCT in volunteers.

For the axial scan, Feldkamp artifacts were visualized as high-frequency streak-like artifacts that are oriented horizontally at the edge of the scan region in the phantom study**.** Similar results were obtained with the volunteers in soft-tissue regions near either bony structures or air pockets**.** Feldkamp artifacts with the 256MDCT can lead to misdiagnosis if not correctly identified and minimized via helical scanning**.** Image noise was less for axial than helical scans, while SSP was better with helical than axial scans**.**

Feldkamp artifacts observed in the 256MDCT images, however, did not generally affect the interpretation of images**.** The 256MDCT promises more accurate diagnosis, and will provide volumetric cine images of wider cranio-caudal coverage, enabling new applications of CT.

MO-D-330A-06

Development of the X-Ray Detector with Sequential Readout Circuits for Multidetector-Row Computed Tomography

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Purpose: To develop a low-cost Xray detector with sequential readout circuits, to realize enough low noise for multidetector-row computed tomography(MDCT), and to evaluate image quality**. Method and Materials:** We have developed an X-ray detector that has a MOS-switch for each pixel, connects many pixels of a common column with the electric readout circuit, and outputs the signals of these pixels from one circuit by turning on lines of switches in order**.** It has fewer readout circuits than a conventional MDCT detector, but new design is necessary to realize enough low noise for MDCT**.** First, to make the required noise specific**,** we simulated the relation of the detector noise and image noise (simulation(A))**.** Second, to consider how to realize it, we simulated the detector noise with the circuit noise model (simulation(B))**.** Third, we constructed the detector in order to evaluate its noise**.** Last, we developed a test CT system with these detectors to evaluate image noise with phantoms**. Results:** The result of the simulation(A) indicated that detector noise had to be less than about 10-k rms electrons, and we found to be able to achieve it by optimizing the circuit parameters of the low pass filter and the data line as a result of the simulation(B)**.** We constructed the detectors with these parameters to evaluate these noise, and it turned out that it was about 10.5-k rms electrons and the required noise was achieved**.** Moreover, the result to evaluate the noise from images with phantoms indicated that the main was X-ray quantum noise and the detector noise was low enough to be ignored when the object was a cylindrical water-filled phantom less than about 30 cm in diameter and the slice thickness of the images was 0.625 mm**. Conclusion:** We developed a low-noise X-ray detector with sequential readout circuits for MDCT.

MO-D-330A-07

A Stationary Scanning X-Ay Imaging System Based On Carbon Nanotube Field Emitters

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Purpose: Most tomographic imaging systems available today use a single x-ray source and multiple projection images are obtained by rotating the x-ray source around the object**.** Therefore the data acquisition rate is limited by the gantry rotation speed, which is approaching the physical limit**.** We proposed to develop a novel stationary scanning x-ray imaging system based on carbon nanotube field emission x-ray (FEX) technology**.** Instead of a single x-ray source the proposed system is based on a multi-pixel FEX source**.** The new scanner promises a dramatically faster data acquisition rate by reducing or totally eliminating the mechanical motion**. Method and Materials:** We have constructed a prototype stationary scanning x-ray imaging system with an array of 9 individually addressable x-ray source pixels, each of which can produce a different projection image of the object**.** The core of this novel x-ray imaging technology is a gated carbon nanotube field emission cathode array**.** By programming the gate voltage of the cathode array, the multi-pixel x-ray source can generate an electronically triggered scanning x-ray beam and produce multiple projection images from different viewing angles without mechanical motion**.** A Hamamatsu C7921 flat panel x-ray sensor was used to collect all 9 projection images**. Results:** Tomosynthesis images of a mouse and a standard breast-imaging phantom (Stereotactic Needle-biopsy Tissue Equivalent Phantom, Nuclear Associates, NY) using the prototype stationary scanning x-ray imaging system are acquired**.** Tomosynthesis reconstructions were applied to the breast phantom**.** The slice images reconstructed using an iterative reconstruction algorithm clearly show the internal structures of the breast-imaging phantom at different depths**. Conclusion:** We have developed a stationary scanning x-ray imaging system using a carbon nanotube based multi-pixel FEX source**.** The mechanical motion free approach can lead to a faster and simplified tomographic imaging system.

Conflict of Interest: Research partially supported by Xintek Inc.

MO-D-330A-08

Implementing Quantitative Computed Tomography On Multi-Slice Scanners

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Purpose: Implementing Quantitative Computed Tomography (QCT) on Multi-Slice Computed Tomography (MSCT) scanners requires investigating the effects of axial vs**.** helical scan modes and protocol parameter variations on quantitative data**.** While previous work in this area focused on single-slice axial techniques, technological developments in

Computed Tomography (CT) justify more complex assessment. **Method and Materials:** All scans were obtained using two phantoms designed for bone mineral (BM) densitometry: a reference phantom (three different density cores) and a QA torso phantom. Both phantoms have known properties and are required for long-term quantitative BM density assessment. The scan acquisition parameters that were varied included kV, mA, rotation speed, pitch, image thickness, detector configuration, reconstruction algorithm, table height, and tube temperature. To assess long-term scanner drift, the QA Torso phantom was scanned multiple times over three months on each of seven MSCT scanners (five GE Lightspeed-16s, one GE Lightspeed Qx/i, and one GE Lightspeed-Plus). The daily variability of the individual MSCT scanners and scanner-to-scanner variability was determined by coefficient of variation (mean/variance) from the QA Torso phantom data sets over time. All data were collected and analyzed in Hounsfield Units (HU) to provide insight about variations upstream of the actual BM density analysis through commercial software. **Results:** This study found no significant difference ($p > 0.05$) in mean HU between phantom images obtained using axial and helical scan mode, or when varying most of the other scan acquisition parameters. However, varying kV and reconstruction algorithm did result in significant ($p<0.0001$) quantitative shifts. Preliminary data indicated daily variability of 0.8% - 1.9% and scanner-to-scanner variability of 1.4%.**Conclusion:** MSCT systems can be optimized for use in determining the BM density of a vertebral body, provided very careful control of scan acquisition protocol is observed.

MO-D-330A-09

Performance Evaluation of Different Fanbeam Algorithms in the Presence of Noise

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Purpose: Different fanbeam reconstruction algorithms are being evaluated and the noise performances of these algorithms are compared at equivalent MTF. **Method and Materials:** The fanbeam reconstruction algorithms under comparison are FBP with Parkers smooth weighting (PFBP), LCFBP, DFBP, reconstruction algorithm by Noo et.al and exact reconstruction algorithm by Kudo et.al . The MTF from the five different algorithms were plotted and compared. In order to establish the basis for an unbiased comparison of the noise variance between different algorithms, we established the condition of equivalent spatial resolution. To achieve this, a window function was applied to the ramp filtering kernel before backprojection for PFBP, LCFBP and Kudo's algorithm. A homogenous phantom was numerically simulated and Poisson noise with N_0= 2e5 was added to the projection data. The images were reconstructed from projection data with and without the Poisson noise added. These images were then subtracted from each other to result in a subtracted or pure noise image. The variance in these noise images over five different ROIs was subsequently compared. FBP with Parkers smooth weighting was chosen as the gold-standard and percentage decrease in variance in the images reconstructed using other four algorithms with respect to that of PFBP was tabulated. **Results:** The results showed that the new reconstruction algorithms had better noise performance than state-of-the-art reconstruction algorithm (PFBP) after establishing the condition of equivalent spatial resolution. DFBP and exact reconstruction algorithm by Noo performed much better than the other three algorithms. Equal weighting scheme utilized definitely improved the noise performance over smooth weighting. DFBP showed a decrease of variance by about 23 % compared to PFBP. **Conclusion:** The reduction in noise variance theoretically leads to a radiation dose reduction by about 23 %. This will be of significant importance especially in pediatric imaging.

Imaging Symposium — Room 330 D

Molecular Imaging I: The Physics of Molecular Imaging

MO-D-330D-01

Molecular Imaging I: The Physics of Molecular Imaging

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The first day of the Molecular Imaging Symposium (MI-1) will focus on the technology aspects of molecular, functional, and small animal imaging. Modalities which will be discussed include micro-CT, micro-PET, and high resolution MRI for small animal imaging. The presentation on micro-CT technology will include an introduction to the basic requirements of the scanner hardware, examples of the images and biological applications in which micro-CT is useful, and the radiation dose to the small animal undergoing micro-CT will also be discussed. Micro-CT techniques require longer acquisition times than human scanners, and thus maintaining the animal in a viable but motionless state is of clear importance. Therefore, issues surrounding animal support including anesthesia and respiratory gating will also be presented.

Micro-PET systems are widely used in small animal imaging for genome research, and represent probably the mainstay of truly molecular imaging modalities at this point in time. The presentation on micro-PET will include a description of micro-PET scanner hardware, a discussion of PET-radiotracers, and an overview of current small animal PET systems. The limitation of current micro-PET system design will be discussed, and ideas for overcoming some of these limitations will be presented.

High resolution MRI systems have the benefit of delivering exquisite contrast with excellent spatial resolution, with no ionizing radiation. The presentation on micro-MRI techniques for phenotype imaging will describe the integration of physics, biology, chemistry, engineering, and computer science which is necessary to achieve state-of-the-art small animal MRI imaging. The use of hyperpolarized gases for lung imaging and MR histology will be discussed as well.

The availability of small animal imaging systems across a number of modalities has proved essential for a large number of research applications. The primary goal of MI-1 is to help familiarize medical physicists with the technical design and capabilities of these high resolution small animal imaging systems, and to highlight research applications of their use. Different modalities are used to address different research questions, and this symposium will emphasize the strengths and weaknesses of each modality in regards to various research applications. Differences between animal imaging and human scanners will also be discussed.

Joint Imaging/Therapy Scientific Session — Valencia B

Therapy Localizatoin (Non-Tomographic)

MO-D-ValB-01

Characterization of Cardiac Motion in the Lung Using a Novel Electromagnetic System in An Animal Model

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Purpose: Previous studies have examined the accuracy of the use of three internal AC electromagnetic transponders and wireless tracking system (Calypso® Medical) for tumor localization in prostate cancer. This study focuses on the use of the system to investigate and characterize cardiac induced lung tissue motion to better predict three-dimensional lung tumor position in real-time. **Method and Materials:** Under an institutional approved animal study, three 1.8 mm AC electromagnetic transponders are bronchoscopically implanted in the periphery of the lungs of five hounds. The transponders are positioned in a triangle, each spaced 1-3 cm apart. The transponder positions are sequentially measured every 50 ms at five time points. During each measurement, the subject is stressed with several respiratory patterns. Signal processing of the data involves the design and application of a Butterworth highpass filter to obtain the component of transponder movement due to cardiac motion. **Results:** The data for the 1st three time points of the first animal are presented. FFT spectrum analysis indicated signal frequency components of 13.05 and 123.8 cycles/minute, due to respiration and cardiac motion respectively. Cardiac-induced lung tissue motion was detected in vivo, ranging from 0.0007cm – 0.3592cm, by applying the highpass filter to the data. The motion was smaller on the implant day compared with the other two time points. Moreover, transponder position and distance from the heart had an effect on calculated motion. Finally, breathing patterns also affected the observed motion at a statistically significant 0.1% level. **Conclusion:** Cardiac contractions cause quantifiable motion in surrounding lung tissues that cannot be measured with existing onboard imaging capabilities. The motion varies

depending on transponder position, distance from the heart, breathing pattern, and day of measurement. Though the motion maximum was 3.6mm, this motion could cause imaging artifacts when using respiratory correlates.

Research sponsored by Calypso® Medical Technologies

MO-D-ValB-02

OpenGL Based 2D-3D Registration of a CT Image Dataset With OBI Images

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Introduction. A limiting factor in registration of a three-dimensional (3D) computed tomography (CT) dataset with two-dimensional (2D) x-ray images has been the time-consuming generation of digitally reconstructed radiographs (DRRs). This can be overcome using a commercial graphics card for DRR generation enabling fast, robust, and accurate automatic image-based 2D-3D registration. **Methods and Materials.** For the iterative registration process hundreds of DRRs are created using hardware rendering in OpenGL. Each DRR from a 512x512x100 CT volume is rendered in less than 0.1 seconds using an nVidia 7800GT graphics card. The registration is based on a publicly available implementation of Mattes Mutual Information (ITK, U.S. National Library of Medicine, Bethesda, MD). To improve speed, the registration is performed on a sub-image. A two-step registration strategy is adopted for robustness with the first pass using a larger margin around the sub-image and a down-sampled resolution. A thoracic phantom (Model 602, CIRS, Norfolk, VA) was imaged and setup according to our clinical protocol and then shifted from 0-1.5 cm along each of the major axes. Anterior-Posterior and Lateral kV x-ray images were acquired using a commercial patient imaging system (OBI, Varian Medical System, Palo Alto, CA). **Results:** . The mean registration times were 8 and 16 seconds without and with rotations respectively. We observed a systematic 1.1 mm offset in the longitudinal direction that we believe results from 2.5 mm CT slice spacing and OBI calibration. With this removed the mean three-dimensional distance of the registered positions from the phantom positions was 0.4 mm with the largest disagreement being 0.75 mm. The systems ability to calculate rotations was only tested numerically.
Conclusions. The speed and accuracy of this system demonstrate that it could be a viable tool for reducing daily setup uncertainty by automating the analysis of setup images.

Research sponsored by Phillips Medical Systems.

MO-D-ValB-03

Genetic Evolutionary Taboo Search: A Novel Approach for Optimal Marker Placement in Infrared Patient Positioning

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Purpose: To develop the methods of a novel approach for optimal marker placement in infrared patient positioning. **Method and Materials:** A non-deterministic optimization technique (Genetic Evolutionary Taboo Search, GETS), combining genetic algorithms and taboo search, was implemented. A population-based evolution is generated, where adaptive memory features guide the evolutionary process to thoroughly explore the solution space. Preset taboo solutions are introduced to reject marker configurations resulting collinear from the point of view of infrared cameras. The GETS algorithm was tested on 10 prostate patients: treatment planning CT scans were segmented to provide 3-D representation of PTV (prostate + seminal vesicles), OARs (bladder and rectum) and skin surface model. Segmented data were fed to the GETS algorithm to obtain optimized configurations of markers, minimizing the target registration error (TRE), to be compared to a random configuration. The changes in the optimal marker configuration when OARs are included within the target were also investigated. **Results:** The GETS algorithm yielded a significant improvement in TRE values: optimal configurations ensured a 26.5% mean TRE decrease. Common features in the optimal marker configurations were found for the 10 patients group, being optimized solutions symmetrically distributed, with markers mostly placed on lateral sides. Optimal marker configurations when OARs were included within the target resulted in a similar spatial distribution, if compared to the PTV-only condition. The implemented memory-based design resulted in improved gene expression over the evolution process, with respect to memoryless genetic algorithms. **Conclusion:** The GETS algorithm revealed high performance in solving the optimal marker placement problem, leading to improved marker configuration for stereophotogrammetric patient positioning in radiotherapy. Memory features ensured enhanced capabilities in exploring the solution space, if compared to conventional genetic optimization. The application of the new algorithm to a 10 patient group provided practical indications toward better marker placement for prostate cases.

MO-D-ValB-04

Internal-External Correlation Investigations of Respiratory Induced Motion of Lung Tumors

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Purpose: In respiratory-gated treatments, the successful delivery of the planned dose distribution and sparing of the health tissue is highly dependent upon the assumption of a strong correlation between the external motion and the internal tumor motion. We will present a new internal/external correlation study based on a unique data set. **Method and Materials:** Radiopaque fiducial markers inside or near the target were implanted and visualized in real time by means of stereoscopic diagnostic x-ray fluoroscopy. The fluoroscopic images were recorded continuously in synchronization with an external respiratory motion monitoring system. A data analysis methodology was developed in order to assess the correlation of the external breathing motion with the internal 3D position of the implanted fiducials. The methodology is based on a dynamic correlation technique and used to extract global correlation parameters as well as to reveal their instantaneous behavior. **Results:** We have found that in some cases, the poor internal/external correlation is caused by a time mismatch between the motion of the internal fiducial markers and the external breathing motion. For some cases, there is a sizeable time delay between the internal tumor motion and the external motion of up to 0.8 seconds, revealing that internal-external motion coupling is dependent on the tumor position. We have also found that the time delay itself is time-dependent. **Conclusion:** The proposed technique reveals one of the causes for poor internal-external correlation and it could be used to improve the current gated treatment methodology by combining the amplitude gating technique with the measured time-delay. In the course of these investigations, we also found that our technique can reveal difficulties in extracting the underlying time delay (due to its own time dependence) and that one has to be careful of how the time delay is implemented for gating.

MO-D-ValB-05

Commissioning An AC Electromagnetic Localization System for Radiation Therapy

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Purpose/Objective: To establish a commissioning and acceptance test protocol for an AC electromagnetic tracking system for use in target localization and tracking during radiation therapy. (Calypso® 4D Localization System, Calypso Medical, Seattle, WA). **Materials/Methods:** Following installation of infrared cameras and electromagnetic system, compatibility tests were made to ensure the system did not interfere with radiation output, MLCs or IMRT field fluence. The collision space between the linac and the Calypso System was evaluated. System verification included calibration using software and calibration tools, one of which has embedded RF transponders and optical reflectors. End-to-end testing to assess localization accuracy included CT scan of a radiographic phantom with RF transponders, creation of four Calypso Plans, data entry to the Calypso System and execution of treatment sessions. Tracking accuracy was measured using a precision translation table for orthogonal

motions ± 5 mm. **Results:** Calypso System did not affect normal clinical operations of radiation output, MLC, or IMRT field segmentation. Overall accuracy on ten systems at five institutions and 40 treatment plans was 0.068 ± 0.027 cm, incorporating contributing errors from the CT scans, identification of transponders in the phantom, and effects of radiation dose delivery. With stable environment, no systematic drift was noticed over 30 minute. Translations of precise increments from -0.50 cm to +0.05cm were accurately tracked with error of 0.00cm, -0.02cm and 0.01cm (lat, long, vert). The system maintained accuracy with monthly optical calibrations. Changes in system readout of ±0.05 cm (readout quantization) were noticed at certain gantry angles. **Conclusion:** Evaluations demonstrate the AC electromagnetic system with wireless transponders can be integrated into the radiotherapy environment with existing instrumentation and operates within the designed accuracy specification. **Conflict of Interest:**
Work supported by Calypso Medical Technologies.

MO-D-ValB-06

Concurrent Tracking and Fluoroscopic Imaging of Implantable Wireless Electromagnetic Transponders

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Purpose: Multiple technologies are being utilized to improve real-time tumor tracking. To date, there have not been methods to prospectively compare different technologies with realistic tumor trajectories. We evaluated the capabilities of the Calypso® Medical 4D Localization System (Calypso Medical, Seattle, WA) and Varian Trilogy System (Varian Medical Systems, Palo Alto, CA) fluoroscopy in tracking dynamic objects.
Method and Materials: Initially, a quality assurance fixture containing three implantable transponders was moved by an in-house developed 4D phantom through an ellipse and a non-uniform human lung tumor path modeled with CT imaging and spirometry. Subsequently, three transponders that had been implanted in a canine lung were tracked. In both experiments, the transponders were fluoroscopically imaged on a Trilogy system while simultaneously being tracked by the Calypso® 4D localization system. The fluoroscopic images were recorded and later analyzed using a custom-written (MATLAB) image processing program to determine the transponder projection positions with respect to time. The trajectories derived from the fluoroscopic images were synchronized with and compared to the Calypso System position data. **Results:** The root mean square (RMS) position differences were less than 0.03 mm for all tested measurement system combinations. While both were small, the Calypso System RMS error was slightly lower than that of the fluoroscopy when compared against the 4D phantom positions. Of the three trajectories, the RMS error between imaging modalities was largest for the patient trajectory and smallest for the ellipses. **Conclusion:** This work indicates that both tracking methods provide excellent positioning accuracy. Although the accuracy discrepancy between the two systems is negligible, the Calypso® System also offers the ability to localize in three dimensions and has the advantage of being able to track a target continuously without the use of ionizing radiation. **Conflict of Interest:**
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MO-D-ValB-07

Comparison of Inline and Orthogonal Imaging and Treatment Beam Geometries for Monitoring the Motion of Implanted Markers

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Purpose: The purpose of this study is to investigate the accuracy of different 2D methods monitoring implanted markers, compared to 3D method for real-time tumor tracking radiotherapy. The different imaging-treatment beam geometries were the imaging beam parallel to treatment beam (inline) and orthogonal to treatment beam.
Method and Materials: The 3D motion datasets of ten patients from Cyberknife treatments were used. For given beam angles, the positions of implanted markers were calculated and its geometric uncertainty was quantified for two 2D monitoring methods. Since neither can monitor the motion of markers in the imaging beam axis, the geometric errors were determined in that direction with respect to the treatment beam. Assuming that 3D pre-treatment online positioning was performed and thus errors are predominantly random, treatment margins due to the limitations of 2D methods were quantified. For the orthogonal monitoring, margin, $M=1.65\sigma$, was used with the assumption of zero systematic errors; while for the inline, the required margin can be calculated by integrating the probability density function of the geometric uncertainty with the dose fall-off along the beam direction. **Results:** In terms of couch motion, the positioning uncertainty is lowest for coplanar treatments, consistent with predominantly superior-inferior motion. Regarding gantry angles, it is lowest for lateral beams, consistent with the smallest left-right motion. The average positioning uncertainty along the imaging beam axis is 0.05-0.16cm (1 SD) with maximum values for individual patients ranging 0.09-0.33cm, which result in 0.08-0.26cm margins for orthogonal monitoring.**Conclusion:** The impact of the geometric relationship between the imaging and treatment beam has been studied by quantifying the error from out of plane motion for inline and orthogonal imaging-treatment geometries. The errors for inline geometry result in negligible additional margin required. In the absence of other errors, the orthogonal monitoring contributes up to 0.26cm to the total margin.

MO-D-ValB-08

Fluoroscopic Tracking of Lung Tumor Mass Without Implanted Fiducial Markers

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Purpose: To develop techniques for direct lung tumor tracking in fluoroscopic images without implanted markers. **Method and Materials:** During the patient setup session, a pair of 15 second orthogonal fluoroscopic images are taken and processed off-line to generate reference templates. Each breathing cycle is divided into 12 phase bins. Setup image frames falling in a specific bin are motion-enhanced and averaged, and an ROI that contains the tumor is selected to be the reference template for that phase bin. Each reference template corresponds to a tumor position in the image. During the treatment, as soon as a fluoroscopic image is acquired, the cross-correlation score between each reference template and this image is maximized by allowing small shifts of the template in both X and Y directions. Then the tumor position is derived by averaging the tumor centroid coordinates in those templates of high scores (above 85% of the maximum score). For comparison, tumor position in each image frame was also marked by a clinician. **Results:** We tested our algorithm on six sequences of fluoroscopic images from six lung cancer patients. The automatically detected tumor centroid coordinates agree well with the manually marked results, with an average error of 1 mm. **Conclusion:** This study demonstrates the feasibility of tracking lung tumor mass in fluoroscopic images without implanted fiducial markers. Future research will concentrate on further improvement of the accuracy and robustness, and reducing the computational cost.

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MO-D-ValB-09

Residual Motion of Lung Tumors in End-Of-Inhale Respiratory Gating

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Purpose: The intention of this study is to determine whether previously observed large external surrogate residual motion at end-or-inhale (EOI) translates into large tumor residual motion, and if improving the reproducibility at this phase can lessen the internal residual motion. **Method and Materials:** We simulate gated treatment at the EOI phase, using a set of recently measured internal/external correlated patient data. The 3D locations of internal fiducial markers placed near the target are tracked in real-time with stereoscopic x-ray fluoroscopy. An external surrogate respiratory gating system is synchronized with the fluoroscopic unit so that the log files contain the three-dimensional marker position and the abdominal surface position at every time point. The internal and external measurements are taken even when the MV beam is gated off, throughout each treatment, so large amounts of internal/external-correlated

data were collected. **Results:** We found that under free-breathing conditions the residual motion of the tumors is much larger for EOI phase than for end-of-exhale (EOE) phase. The mean value of residual motion at EOI was found to be 2.2 mm and 2.7 mm for amplitude and phase-based gating, respectively; and, at EOE, 1.0 mm and 1.2 mm for the same quantities. However, the residual motion in the EOI gating window is correlated well with the reproducibility of the external surface position in the EOI phase. Using the results of a published breath-coaching study, we deduce that the tumor residual motion at EOI would approach that at EOE under breath-coaching conditions. **Conclusion:** We conclude that the same reproducibility of tumor location can be achieved at EOI as at EOE if breath coaching is implemented. Based on these results, we believe that inhale gating is preferable to exhale gating as long as proper margins are employed and breath coaching is performed.

Joint Imaging/Therapy Symposium Valencia A
Patient Motion Modeling & Adaptive Planning Optimization for Radiotherapy

MO-D-ValA-01
Modeling & Characterization of Respiratory Motion

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A quantitative understanding of respiratory motion is critical to improving radiation therapy for lung and upper abdominal cancers. Breathing motion impacts the quality of diagnostic and treatment planning images, causes conformal therapy portals to be larger than the cross-sectional projection of the tumor, and increases irradiated normal organ volumes. Methods intended to reduce or eliminate the impact of breathing motion have been proposed, including breath hold, linear accelerator gating, and tracking either using the linear accelerator or the patient support assembly. A quantitative model of the patient's breathing motion, both tumor and normal organs, is necessary to optimize the gating or tracking methods.

The form of the respiratory model will depend on the ultimate use of the model. In the case of radiation therapy, we are interested in understanding the positions of the tumor and normal organs as a function of time, because our radiation delivery systems operate as a function of time. However, breathing is not sufficiently reproducible to use time directly as the independent model variable. A different, time-dependent metric needs to be selected as the quantity that will be characterized as a function of time and, during acquisition of the motion model data and radiation treatment, be monitored. The metric needs to be: easily measured, quantitative, reproducible, and correlated with breathing motion. Metrics that have been proposed include abdomen or thorax height, abdomen circumference, and spirometry-measured tidal volume.

The motion model requires input data to provide the patient-specific parameters. The input data is typically derived from CT scans that are acquired while the patient undergoes simultaneous monitoring of the metric. This process is labeled "4D CT" in that multiple CT scans are acquired at each location, each scan acquired at a different time. CT scans are typically reconstructed or resorted at a variety of breathing phases. The reconstructed CT scans are then used to determine tumor and normal organ positions as a function of the breathing metric.

In the use of respiratory motion modeling there are some confusing and overlapping uses for the word "phase" that are worth differentiating. Firstly, the use of the term "breathing phase" is used to describe a general part of the breathing cycle, such as mid-inhalation. Secondly, "phase angle" is used to describe a hypothetical angle used when the breathing cycle is described as a periodic function of time, and finally, "phase" itself is used for any quantitatively defined breathing state.

Prior to the development of a biophysically based breathing motion model, there have been two competing methods for describing the behavior of the metric as a function of time; phase-angle and amplitude. Phase-angle descriptions divide the breathing cycles between selected breathing phases, for example, inhalation. The time between successive inhalations is recast linearly as an angle from 0 to 2π (alternatively, some investigators separate the inhalation and exhalation processes, placing 0 and π at inhalation and exhalation, respectively, with linear time interpolation between these breathing phases). In the phase-angle approach, each inhalation and exhalation is treated equally, irrespective of the depth of breathing, but the model can accurately characterize variations in breathing frequency (at least retrospectively). In this model, the description of motion as a function of phase angle can either be the positions as a function of angle or be written as periodic functions with parameters that provide the positions. The phase-based process is capable of describing the hysteresis-like motion of lung tumors well, but is not capable of adequately describing variations in breathing depth. Patient breathing training is often employed to reduce variations in breathing depth.

Amplitude-based methods describe the tumor and organ positions as a function of the metric's amplitude, or numerical value. The time-dependence of the breathing cycle is taken from the time-dependence of the metric amplitude. The amplitude-based approaches are capable of describing variations in breathing depth, but because modeling of hysteresis requires degeneracy in tumor positions as a function of amplitude, hysteresis is not easily described using the amplitude models.

While both amplitude and phase-based models have been utilized to define and describe breathing motion, neither can adequately model even the simplest breathing motion, namely the amplitude-variable hysteresis motion of lung tumors and normal organs that is known to exist. Recently a breathing model has been proposed that describes tissue positions as a function of tidal volume, namely the amount of air inhaled and exhaled during the breathing process. The model assumes that lung tissue positions vary as a function of tidal volume, or in other words, the deeper the breath, the farther the tissues move in their trajectories. Hysteresis is hypothesized to be due to pressure imbalances within the lung tissues that create the variations in trajectory between inhalation and exhalation. The pressure imbalances are assumed to be linearly proportional to the airflow (time derivative of the tidal volume). The position of a piece of lung tissue is therefore a function of its location at a reference breathing phase (e.g. tidal exhalation), the tidal volume and airflow relative to the reference breathing phase. Incidentally, while tidal volume has been used as the metric, any metric that is proportional to tidal volume and its temporal derivative can be used as the metric. For example, published reports indicate that abdomen height is linearly related to tidal volume for quiet respiration.

Understanding the variables that govern respiratory motion is insufficient to describe the positions; a mathematical model is still required. The simplest, namely a linear relationship between position and tidal volume and position and airflow, where the two position components are treated as independent, has been used and appears to provide good descriptions of breathing motion, although supporting data is still limited.

The process of modeling breathing motion is still in its beginning stages, but there are promising approaches being studied. Assuming that the models can accurately describe breathing motion, they will be key components in the treatment planning process.

MO-D-ValA-02
Patient Motion Modeling & Treatment Adaptation

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Patient anatomical variation during the radiotherapy course can be modeled using a stochastic process. In this process, spatial position of each subvolume in patient organs of interest is defined as a random vector described using a probability distribution function (pdf). Two main parameters, the mean and the standard deviation, of the pdf have been historically used to characterize patient anatomical variation during the radiation treatment. It has been demonstrated that treatment dose distribution in an organ of interest can be evaluated approximately using these two parameters alone, without the full knowledge of organ motion distribution. The approximation is, however, dependent on the scale of the standard deviation as well as the number of treatment delivery fractions. It is straightforward to estimate these two parameters if patient anatomical variation process is stationary. In this case, the two parameters are constants or time-invariance during the treatment course. However, the estimation will be relatively difficult if patient anatomical variation process is non-stationary.

Patient anatomical variation in radiotherapy can be systematically managed using image feedback adaptive treatment technique. The fundamental difference between adaptive treatment technique and other image-guided techniques is the use of patient-specific treatment information. Adaptive technique intends to use all patient-specific dose information - including what has been delivered in the previous treatments, what can be delivered at the present treatment, and what would be delivered in future treatments - in the design of treatment plan. Therefore, treatment plan designed in adaptive radiotherapy is called 4D adaptive plan, which is in principle a treatment control law to manage treatment process. Mathematically, treatment control law is a spatial mapping from the parameter space of patient variation to the parameter space of treatment delivery control, which can be determined including the patient variation in the planning optimization or inverse planning. The objectives in adaptive planning optimization are constructed based on a selection of control strategies that could be either the online or the offline with one control action, multiple actions or continue actions. Selection of control strategy and number of control actions is, of course, dependent on the nature of patient variation process as well as the estimation uncertainties, and has to be determined considering also the clinical practice.

The lecture will provide an overview of the models and characteristics of patient anatomical variation process during the radiotherapy, the 4D dose summation methodology and the strategies of adaptive treatment process.

Educational Objectives:
1. Understand the characteristics and dynamic model for patient anatomical variation during the course of radiotherapy
2. Understand the model and methodology of 4D dose summation
3. Understand the options of control strategy for image guided adaptive radiation treatment

MO-D-ValA-03

Inverse Planning Optimization with Organ Motion Probability

T Bortfeld*, A Trofimov, T Chan, B Martin, H Paganetti, S Jiang, Massachusetts General Hospital, Boston, MA

Organ motion blurs dose distributions. The blurring can be described in a statistical way by use of a motion probability (density) function (PDF). The motion-blurred dose distribution is obtained by a convolution of the "sharp" (static case) dose distribution with the motion PDF. This holds true for both inter- and intra-fraction motions. In the case of intra-fraction motions an "interplay" effect is superimposed on top of the blurring effect. It has been shown that the interplay effect averages out during the course of a fractionated treatment, and that it is usually negligible after a typical number of fractions. The convolution model relies on the linear superimposition principle, which holds true for dose values but not for the biological effect. This issue has recently been addressed and will be discussed.

Several investigations have now looked at the feasibility of un-doing the motion blur through the use if intensity-modulation. In principle it should indeed be possible to de-convolve the motion PDF from the intensity maps, in order to compensate motion effects. This approach has been called 4D optimization or 4D inverse planning. Motion de-convolution cannot, however, compensate motion effects exactly and it cannot be applied in a naïve straight-forward way, because that would lead to undeliverable intensity maps with sharp spikes and negative values. The method of choice is rather to include the motion PDF in the IMRT optimization process. It has been shown that this can indeed yield a surprisingly high degree of motion compensation and it can even compete with other motion compensation methods such as gated delivery. However, this is only true if the motion characteristics (the PDF) are known with great precision. If the actually realized motion PDF deviates substantially from the planned PDF, the method becomes less useful and can, in principle, make things worse.

More recently, uncertainties in the knowledge of the motion characteristics have been taken into account by use of robust optimization techniques. With these one can now compensate for motion effects in an approximate way for a large class of motion characteristics. In terms of the sparing of normal structures, the results are in between the use of conventional margins and the idealistic case of perfect motion compensation. The resulting intensity maps exhibit "horns", which can shave off a few mm from the margins.

Educational Objectives:
1. Understand the concepts of motion blur and PDF
2. Understand the idea of de-blurring a dose distribution through "4D" motion optimization
3. Be able to discuss the relative potential and limitations of 4D motion optimization in comparison with margins and gating

Professional Session Room 230A

Professional - Proffered Session

MO-D-230A-01

A Nontraditional Method of Providing Radiation Protection Instruction at a Large Health Science Center

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Purpose: To test the hypothesis that the combined online/lecture format was as effective as the lecture-only format for students who took the University of Alabama at Birmingham (UAB) radiation safety course.

Method and Materials: In the 4th quarter of 2001 the University of Alabama at Birmingham (UAB) converted its traditional classroom radiation safety course, taught exclusively in a classroom setting four times each year, to a combined online-classroom format in which the majority of the course is taught online. This change was instituted in an effort to minimize the time spent in the classroom for UAB research personnel. This format should provide the additional benefit of self-paced instruction for course participants. A statistical analysis was performed on the average first-attempt test scores of the tests (number of tests=334) taken during a two-year period before the online transition (average score=75.5), and the average first-attempt test scores of the tests (number of tests=359) taken during a two-year period after the online transition (average score=74.1.) **Results:** A two-tailed Student's t-test was performed on the data. The t-value was 1.73, and P(T<=t) was 0.083. At α=0.05, the null hypothesis that the two averages are equal cannot be rejected. **Conclusion:** The online course format appears to be as effective a method of radiation safety instruction as the more traditional, exclusively-classroom method of instruction. This presentation also reviews steps under consideration to improve the current online course to make it a more effective tool in radiation safety instruction.

MO-D-230A-02

An Immersive Virtual Environment for Training of Radiotherapy Students and Developing Clinical Experience

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Purpose: Radiotherapy equipment and techniques are rapidly developing and so efficient training is invaluable. However, the demands on clinical systems and the lack of trained personnel make it difficult to achieve. As an alternative approach we have developed virtual reality training tools, fully interactive and operating on a life size scale these can provide valuable experience for students and staff. We designed a study for 42 first year therapist students to investigate the usefulness of our training environment for learning a clinical technique that typically causes problems. **Method and Materials:** We have created a virtual environment that simulates an actual radiotherapy treatment machine, controlled via an actual handheld control pendant. The study was developed to simulate a "skin apposition" electron beam treatment. A virtual patient, based on the visible human female dataset, complete with rectangular markings for a range of different treatment sites, provided a range of treatment scenarios. At the Hull Immersive Visualization Environment (HIVE) we are able to project our graphics display onto a 5.3 m by 2.5 m 'Power Wall' utilizing stereoscopic visualization enabled via LCD shutter glasses. Such immersive interaction techniques (including the use of the Linac hand pendant) add to the user's sense of reality. To provide feedback, we have implemented a 'scoring algorithm' to assess how well the user has set up the beam/ patient. **Results:** The students reported the training environment to be realistic and following its use 93% perceived an improvement in their understanding of this clinical technique and 69% found the control system easy to master. **Conclusion:** Having implemented such training software and hardware we are beginning to

perform academic studies to assess the impact of its use in the educational forum. We wish to understand which areas of multi-discipline training will benefit from such an approach.

MO-D-230A-03

Patient Planning Management System

M Kirk*, J C H Chu, Rush University Medical Center, Chicago, IL

Purpose: The goal is to develop a dynamic automated patient management program. This software will be able to track the status of the patient's treatment plan and remind the responsible parties of intermediate deadlines. Alerts are sent each morning to the radiation oncologist, residents, dosimetrists, and physicists about the current stage of the treatment planning. **Method:** The patient planning management software was written in Visual Basic 7.0 and incorporates Microsoft Excel's spreadsheet. The programs display is viewable over anywhere in the department. The program shows each patient's data in a separate row and color coded according each radiation oncologist. The patient's CT and start date are entered for each patient. The deadlines included are that for the approval of the PTV and normal tissue, plan approval, and completion. The program will change the color of the patient's data from yellow (warning) and red (alarm) based upon approaching deadlines. **Results:** This planning software continuously updates patient information. This program eliminates the time consuming process of paging, emailing, and tracking down responsible parties to communicate completion of various tasks. Since the inception of this software the mean time interval to complete a plan has decreased by 30%. The mean time required to get target volumes approved has dropped 25%. One significant benefit is the 50% increase in time between the completion date and start date. Without an increase the overall planning time, this has allowed more time for physics checks, quality assurance, and therapist review. **Conclusions:**
In the face of increasing patient numbers the dynamic automated patient management software has enabled our department to complete our patient's plans in a more efficient manner. This increased efficiency allows all responsible staff adequate time to complete their responsibilities for each patient.

MO-D-230A-04

Dedicated PET-CT and MR-Simulators in a State-Of-The-Art Radiation Treatment Facility

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Purpose: To provide dedicated, integrated PET-CT and MR simulation and imaging devices in the radiation treatment clinic for purposes of advanced oncologic imaging. **Method and Materials:** A planning team was established for design of radiation oncology facilities as part of a new comprehensive cancer center. Physicist input included emphasis on combined biological-anatomical (termed "bioanatomic"™) imaging for a research program in Bioanatomic Imaging and Treatment (BAIT), provision of state-of-the-art treatment devices for IMRT, radiosurgery, and HDR, and analyses of digital medical informatics. PET-CT and MR simulator specifications were delineated at a time of rapid technology development for both modalities, and included capabilities for gated PET-CT acquisition and high-resolution MR spectroscopy. **Results:** Facility design includes dedicated rooms for Conventional, PET-CT, and MR simulation. BAIT simulator devices selected are 8-slice PET-CT and 3.0T MR, each with "marking" lasers and virtual simulation tools. PET-CT simulation includes respiratory gating. 3.0T MR simulation includes spectroscopic, diffusion, and perfusion imaging. Radiation safety aspects include shielding for ionizing radiation (PET-CT) and radiofrequency and magnetic fields (3.0T MR). PET-CT and MR simulators are centrally located to facilitate patient flow and physician access. PET-CT and MR simulations are being performed under the auspices of multidisciplinary clinical and research oversight committees. Operators are paired as one imaging technologist (PET-CT or MR) and one radiation therapist per simulator. **Conclusion:** Vision for the Bioanatomic Imaging and Treatment Program has been coupled with the opportunity for a new comprehensive cancer center facility to provide multi-slice PET-CT and 3.0T MR simulation in the radiation treatment clinic. Using a collaborative multidisciplinary approach, image-based research protocols have been developed for specific disease sites, and experience is being gained with use of dedicated, integrated PET-CT and MR simulation. **Conflict of Interest:** BAIT Program research partners include Varian Medical Systems and GE Healthcare.

MO-D-230A-05

Medical Error Detection and Reduction Plan in Community Cancer Center

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Purpose: An error reporting program, called the Medical Error Reduction Plan, was developed in our department. The program includes errors made during the patient treatment preparation process and delivery. The purpose of this study is to understand the types of errors, error frequency and trending, correlation between errors, error severity and impact on treatment quality, and to derive an error reduction strategy based on non-punitive principles. **Method and Materials:** The plan supplements all required QA processes and procedures in Radiation Oncology. After patient treatment plan approval, the Therapists Check Station performs a final comprehensive check that includes: plan revision, patient setup, data entered to R&V system, approvals and scheduling. Problems are recorded in a Discrepancy Log Book that includes also errors in simulation and incomplete directives/forms. All these data are presented, discussed and analyzed at the monthly departmental meetings. We have two full years of data combined into the following categories: simulation, planning, approvals, logistics, documentation and treatment. Errors in patient treatments have been recorded in our Department as Unintended Deviations. They are presented on graphs together with data from our error reduction plan. **Results:** During the past two years, 350 errors were reported. Most of them (60%) were clerical, simulation and treatment planning errors accounted for 11% and 17%, respectively. At the end of the analyzed period, there was more than 50% overall reduction of treatment errors. The introduced error reporting program increased personnel alertness to treatment process details. **Conclusions:** The idea of a "user friendly" error detection and reduction program has proven excellent. Despite of multiple QA procedures and the R&V system, the possibility to make errors still exists. It is imperative to detect them before treatment. This process should be ongoing in view of increasing novelty and complexity of treatments.

MO-D-230A-06

Statistical Consistency Reviews (SCR) as a Chart Checking Tool

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Purpose: Chart checking is key in radiation oncology QA. AAPM TG 40, *Comprehensive QA...Oncology*, TG53, *QA for...Planning*, and *ACR Technical Standard...Therapy* address chart checking. They recommend verifying monitor unit (MU) calculations by a second person or method before delivering 3 fractions or 10% total dose. Time-consuming verifications are difficulty for multiple beam, heterogeneity corrected 3D and IMRT isodoses. We investigate *statistical consistency reviews* (SCR) of common treatments as one of several chart-checking tools. **Method and Materials:** We collect data (gantry and collimator angles, SSD, field sizes, weights, fractions, dose/fraction, depths, outputs, MUs) for sites. We investigate parameter statistical consistency for the same treatment to similar patients. We report prostate four field treatments (66.6 Gy or 74 Gy/37 Fx) and IMRT five-field (0, 75, 140, 220, 285 degrees) treatments (76 Gy/38 Fx). **Results:** Four field prostate treatments are surprisingly consistent. SSDs varied about 3% and MUs about 6%. Average AP SSD was 87. 9 +/- 1.9 cm (2%) requiring 47.4 +/- 2.5 (5%) MU for 45 cGy. Average lateral SSD was 80.7 +/- 2 cm (2.5%) yielding 63.3 +/- 2.5 MU (4%) for 45 cGy. IMRT treatments MU variations were about 20%. **Conclusion:** How to use these data? Rather than check our historically accurate algorithm calculations against another algorithm, we review four-field prostate MU calculations against statistical norms. A recent patient's AP 57 MU were greater than three standard deviations above the norm, 47 +/- 2.5 MU. His AP 79 cm SSD was well below the norm, 87.9 +/- 1.9 cm. A planning error? No, he was just obese, but it illustrates the value of knowing average parameters. IMRT plans appear more consistent than expected; SCR may have value for IMRT plan reviews. Statistical data will be presented for other sites (breast, head/neck, etc.) commonly treated with consistent methods.

MO-D-230A-07

Analysis of Couch Sag and Couch Deflection in Several EXACT Couches

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Purpose: To measure couch sag and couch deflection in several EXACT Couches. **Method and Materials:** Couch sag was evaluated for EXACT Couches at three positions: tip, center and base with the couch fully extended in treatment position. In each case, measurements were made with no weight and with 84, 142, and 319 lbs uniformly distributed over the couch surface. Couch deflection was evaluated with SSD readings to the couch surface using the mechanical backpointer at isocenter and digital read out. Measurement were repeated with the couch at nominal SSDs of 100 cm, 110 cm and 120 cm and with rails closed together in the middle. Same measurements were performed with Picker CT couch for comparison. **Results:** We found 9 mm deflection from the tip to the base of couch (fully extended) with no weight on the surface. According to Varian service personnel, design of EXACT Couches follows IEC specification and Exact Couch manufacturers provided a +5mm deflection to counter weight the patient's weight. Our couch was shimmed and brought the sag down to +5mm. EXACT Couch deflection with no weight on surface varied between 5-9mm at five different centers. Sag was same at nominal SSDs. Up to 7mm sag variation was noticed depending upon the weight.
With rails closed together in the middle, about 1mm decrease was noted for the above values. Upto 4mm sag was noticed in CT couch. Unlike Exact couch, CT couch sag decreased at the base. **Conclusions:** Study demonstrated that the +5mm deflection does not completely counter weight the patient's weight for having leveled surface at the isocenter.
2-5mm sag at tip and up to –7mm at base relative to the amount of weight on couch was noticed. In time +5mm-shimmed deflection was deteriorated to +7mm. Same results were obtained when couch was loaded.

MO-D-230A-08

A Technique for Tracking and Predicting Physician Referrals

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Purpose: To create a tool for collecting physician referral data, identifying strengths and weaknesses in physician referral patterns, and for predicting future referrals in real-time. Methods and Materials: Since January 2001, the referring physician was recorded for each patient that was seen for consultation in a radiation oncology department. In addition to the physician, the referring physician group was also recorded. The total referrals for each month were summed for each individual referring physician and physician group. In addition to referral data, physician hospital in-patient admitting data for oncology related diagnoses were obtained from the state's medical statistics. For physicians that have privileges at multiple hospitals, the "Market Share" was calculated. The number of referrals received each month was predicted using a locally weighted regression (*LWR*) model. The regularization parameters of the LWR model were determined through a continuous genetic algorithm that minimized the mean squared error using data not used in the LWR model. To protect confidentiality, a sample data set was crafted to simulate possible radiation oncology scenarios. **Results:** The results of this study are confidential business data, and so, a sample dataset is used to demonstrate referral pattern tracking. The results concluded that 95% of patient referrals originate from one of five specialties, the largest being medical oncology (43%). The top referring group in each medical specialty was responsible for 65% of patient referrals, and refer >95% of their patients inside the same health system. The remaining 35% of the hypothetical radiation oncology's referrals are physicians who practice in multiple health systems. The *LWR* model accurately predicted the number of referrals with a mean squared error of 2.2%. **Conclusions:** The collection and analysis of physician referral data provides a useful tool for maximizing radiation oncology growth and efficiency through known parameters.

MO-D-230A-09

ACR Mammography Accreditation Program''s Early Digital Mammography Results

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The Mammography Quality Standards Act (MQSA) of 1992 requires that all mammography facilities in the United States (including those using full field digital mammography [FFDM] equipment) be accredited by an approved body, certified by the U.S. Department of Health and Human Services (HHS), and receive an on-site inspection by a state agency acting on behalf of the HHS (or by HHS inspectors). The FDA approved the first premarket approval application for a FFDM unit in January 2000. Immediately accrediting these units presented a dilemma for the American College of Radiology (ACR) since, historically, programs are only developed for mature, widely-available technologies, so that reasonable standards may be developed based on expert experience. Consequently, the ACR could not have an accreditation program available for this new technology at the time FDA approved it to be sold in the US. To provide time for accreditation development, the FDA provided a process to exempt FFDM units from the MQSA accreditation requirement if an accreditation program was not yet available for the specific FFDM model. The FDA approved the ACR to accredit the General Electric Senographe 2000D, the Fischer SenoScan and the Lorad Selenia FFDM units in 2003; the General Electric Senographe DS in 2004 and the Siemens Mammomat Novation in 2005. Although some of the accreditation instructions and submissions are different for digital accreditation, each unit is still required to pass clinical image quality, phantom image quality and dose. Data since 2003 shows that the deficiency rate for FFDM units making their first attempt at accreditation is lower than with screen-film applicants (approximately 7% vs. 11%). Accreditation results from over 1200 units at 900 facilities will be presented.

Therapy Scientific Session — Room 224 A

IMRT Verication and QA I

MO-D-224A-01

Packet-Level Quality Assurance of MLC Informatics

D YJ Kim*, SUNY Upstate Medical Univ, Syracuse, NY

Purpose: To develop a system for real-time auditing and archiving of MLC treatment data, both static and IMRT, through the passive detection and reconstruction of packet-level network traffic between the linac control computers and the central database server. **Method and Materials:** The three computers under observation are the control computers for a Varian 21EX (120-leaf dynamic MLC) and a Varian 2100-2 (52-leaf static MLC) and the central database server running Varis 7 clinical informatics software. The observing system consists of a Linux-based PC connected via Ethernet to modified network segments of the two linac control computers, running the Ethereal and Snort open-source network analysis tools in addition to database and web services. After detailed observation of the computers' data transfer protocols and MLC data formats, the system was configured to passively monitor Ethernet traffic during clinical operations and selectively record only those packets containing specific treatment session, field, and MLC details to a database. Finally, a custom PHP-MySQL script was written to reassemble, convert, and present this binary data in human-readable, web-accessible format. **Results:** The system successfully reconstructs and stores the network-detected MLC configurations for all fields in a treatment fraction, seconds after the patient file is opened at either treatment computer. Its application to IMRT QA is both real-time MLC auditing (e.g. verify that the MLC data received by the server matches that of the previous fraction, 10-15 minutes before treatment delivery) and as an off-line archive of transmitted MLC configuration data. **Conclusion:** This system demonstrates that the examination of network traffic can provide a useful and innovative tool for radiotherapy QA. Its informatics-centered approach to IMRT QA contrasts with and complements the numerous delivery-centered techniques, which focus on dosimetric verification of MLC sequences that are known to have been transmitted to the linac computer without error.

MO-D-224A-02

Clinical Experience in Using EPID for Quantitative Verification of IMRT Dose Distributions

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Purpose: The purpose of this work is to investigate the advantages of using an electronic portal imaging device (EPID) as part of our clinical IMRT QA procedure. We present our experience with the quantitative verification of the planar dose distribution for patient-specific IMRT treatment plans. **Method and Materials:** Our treatment machines which are used for IMRT delivery are equipped with amorphous silicon EPIDs. The planning system used for routine IMRT treatment planning calculates planar dose at a predefined source to plane distance (SPD) as part of the EPID-based QA process. For quantitative analysis, dosimetric calibration of the EPID was required, in addition to the standard imager calibrations of the PortalVision imaging device. Basic dosimetric characteristics of the system were initially evaluated using fields with known dosimetry. Absolute dose calibration produces results comparable to ion chamber measurements. The patient IMRT QA fields were delivered prior to treatment and recorded. We have selected 100 cases from our routine IMRT case load for analysis using this procedure. ***Results:*** The verification of dose distributions was performed using portal dosimetry in Vision, after beam delivery. The overlay of the acquired and the calculated planar doses as isodose lines provided a useful qualitative evaluation. For further quantitative analysis, the gamma relative evaluation (GRE) was used on each field for every patient. The GRE scores were normally greater than 0.99 for prostate patients and greater than 0.98 for Head and Neck cases or large pelvic fields. **Conclusion:** Planar dose verification is an important part of the IMRT QA procedure. With the aid of portal dosimetry using EPID, the QA of an IMRT plan can be performed in 30 minutes, saving considerable time compared to film dosimetry. With proper dosimetric calibration, quantitative analysis further ensures excellent quality assurance of IMRT planning and delivery.

MO-D-224A-03

Dependence of Planar IMRT QA On MLC Positional Inaccuracies

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Purpose: This work aims to investigate the sensitivity of IMRT QA done by means of planar dosimetry to MLC positional inaccuracies. Also we propose an accurate method for measurement of MLC positioning errors using the 2D diode array. **Methods:** A method to measure the MLC position errors by using 2D-arrary of 455 diodes (MapCheck, Sun Nuclear) is developed. Our method utilizes the fact that each diode's signal will be most sensitive to the MLC position error when its center coincides with the edge of a MLC leaf where a small deviation from the accurate position produces sharp increase or decrease in the diode output. We designed various multi-segmented test patterns based on this principle that can evaluate the MLC deviations with sub-mm accuracy at multiple MLC banks simultaneously. By using this information as a deviation histogram, we created deliberately erroneous IMRT fields with varying standard deviations of MLC leaf position error. MapCHECK planar dose analysis is performed and the sensitivity of the IMRT QA procedure to MLC position inaccuracy using MapCHECK device is evaluated. **Results:** Our results indicate that for SIEMENS Primus and MD machines, the MLC positional errors show a standard deviation of about +/- 0.7mm. Right after the MLC calibration, this deviation might reduce to 0.55mm. It has been found that a single leaf position can vary by as much as 1mm between two consecutive measurements. Fields with less number of segments that are generated by Direct Aperture Optimization are found to be less sensitive to these errors by measurements with deliberately modified fields with random MLC inaccuracies. **Conclusion:** A method to accurately quantify MLC position is proposed and used to obtain a distribution of leaf position errors for many leaves at multiple banks. The sensitivity of planar dosimeter to the MLC positioning errors is investigated.

MO-D-224A-04

EPID Transmission Dosimetry for QA Use in Adaptive Radiotherapy

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Purpose: Radiotherapy patients treated for H&N cancer often lose weight and have shrinkage of their tumors causing drastic anatomical changes. This can result in changes in dose distribution with respect to PTV coverage and OARs. Monitoring these changes is difficult and presents QA problems for IMRT treatments. In this work we develop a method to monitor H&N thickness changes and correlate with changes in dose distribution. **Method and Materials:** Wax was applied to the neck region of an anthropomorphic phantom in 3-1cm layers. Contours depicting tumor and critical structures were delineated. An IMRT plan was generated to delivery 70Gy to the PTV. The resultant sequence was virtually delivered to the phantom with layers of wax removed. PTV coverage, hot spot, and PRV doses were recorded. A characteristic response curve was generated using the amorphous silicon EPID on a Varian 21EX linear accelerator and slabs of solid water. The phantom was then consecutively imaged removing 1cm layers of wax. All images were acquired for the same number of MU. **Results:** Decreasing the thickness of the neck region bilaterally by 3cm resulted in an increase in 95% PTV coverage from 70Gy to 72.8Gy. The maximum dose in the PTV increased from 80.6Gy to 86Gy. The PTV volume receiving 110% of the prescribed dose increased from 13.4% to 66.6%. The dose to 0.01cc of the spinal cord and brainstem PRVs increased from 45.8Gy to 47.9Gy and 49.7Gy to 51.2Gy, respectively. Using the EPID we were able to predict changes in the lateral dimension of the phantom to within 4mm. **Conclusion:** Our results indicate that anatomical changes during treatment may lead to unacceptable dose distributions. By using lateral EPID images we can monitor the thickness changes (path length) in the H&N region. These changes may be used to determine when re-planning is necessary.

MO-D-224A-05

In-Vivo Dosimetry Using Electronic Portal Imaging and Monte Carlo Techniques

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Purpose: The purpose of this work is to develop and validate an algorithm based on Monte Carlo (MC) simulations to compute the in-vivo dose given to patients during conventional treatments and IMRT from portal images. **Method and Materials:** The exit fluence from primary particles is obtained from the portal image after correction for scatter radiation. The scattered radiation at the portal imager and the spectral energy distribution of the primary particles are estimated from MC simulations at the treatment planning stage. The exit fluence and the spectral energy distribution of the primary particles are then used to ray-trace the particles from the portal imager towards the source through the CT geometry of the patient. Particle weights reflecting the probability of a particle being transmitted are computed during this step. A dedicated MC code is finally used to transport back these particles from the source through the CT geometry of the patient to obtain an in-vivo dose. Only Compton interactions are considered and secondary electron transport is implemented by depositing the dose uniformly on the surface of a sphere of radius corresponding to the electron projected range. This code also produces a predicted portal image which is used as a verification tool to ensure that the dose reconstruction is reliable. The dose reconstruction algorithm was compared against MC treatment planning (MCTP) predictions and against measurements. **Results:** The reconstructed doses and the MCTP predictions in homogeneous and heterogeneous phantoms agree within 1% for simple open fields except in the buildup region and in the penumbra where the agreement is within 9%. Comparison with film-measured dose distribution for IMRT fields yielded agreement within 3 mm, 3 %. **Conclusion:** A novel dose reconstruction algorithm based on MC simulations has been developed and validated in homogeneous and heterogeneous phantoms for conventional and IMRT fields.

MO-D-224A-06

Fast Monte Carlo-Based Computation of ASi-EPID Dose Images for IMRT Treatment Field Through Phantom

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Purpose: During-treatment IMRT dosimetric verification can be accomplished with exit dose portal dosimetry; however, differential beam hardening and patient scatter radiation results in inaccuracies in invariant kernel-based calculation methods. The purpose of this study is to develop an accurate, yet efficient Monte-Carlo (MC) based algorithm to predict during treatment dosimetric aSi-EPID images to compare with measured images for plan delivery quality assurance. **Method and Materials:** To compute EPID images, the VMC++ MC algorithm is used to transport particles through the patient geometry. Particles exiting the patient are scored into 19 energy-differential fluence-matrices at the EPID surface. Computed EPID images are generated by summing the contributions of each fluence-matrix convolved with MC generated mono-energetic energy deposition kernels. Kernel-based method validation was performed for open, MLC-blocked, intensity test-pattern and a prostate-IMRT field with and without a 20 cm thick phantom by comparing with full MC computation of EPID images. Additionally, the prostate-IMRT plan was computed through a pelvic phantom. A cone-beam CT of the pelvic phantom was used for dose computation particle transport. Comparison metrics include image profiles and gamma-metric evaluation. **Results:** For the test fields, kernel-based methods had >95% of voxels with $\gamma<1$ for 1 %, 1mm criteria and >99.1% with a 2%, 2mm criteria with respect to the MC-calculated fields. For the pelvic phantom, 92.6% of pixels had $\gamma<1$ for 1%, 1mm criteria. The systematic discrepancy(~0.5%) is well below the statistical uncertainty(~3%). **Conclusion:** The kernel-based convolution method is comparable in accuracy with full MC while requiring substantially less computation time than a full MC EPID simulation. Image computation time is independent of MC statistical precision and adds <1min to the MC simulation time. Comparison of measured images with MC-computed portal images may be a practical method to perform during-treatment dose validation. **Conflict of Interest:** Supported in-part by Varian Medical Systems.

MO-D-224A-07

A New Software Tool for Quantitative Verification of IMRT Fluence Maps

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Purpose: To provide a mechanism for quantitative verification of each bixel in an IMRT fluence map within minutes. **Method and Materials:** A software tool called Super-IMPOSE (Intensity Map Pre-treatment OverSight & Evaluation) was developed to quantitatively verify fluence maps using an Electronic Portal Imager (EPI). This software imports EPI-measured fluence maps along with TPS-calculated maps and compares them by bixel. We developed a convolution algorithm to correct the raw fluence map for the effects of scatter within the imager, along with an edge detection and registration algorithm. Deviations between the predicted and measured bixel values are displayed as a matrix of percentage deviations, with maximum, mean, and standard deviation values calculated for each row, each column, and the entire map. Clinical applicability was investigated using IMRT plans delivered using a Varian accelerator with aS500 EPI. A set of 16 fluence maps from 6 different patients was selected, spanning a wide range of size and complexity, and employing both 0.5cm and 1cm bixel sizes. **Results:** The mean and standard deviation values for the bixel intensity differences were 1.9% and 1.4% for the 1cm bixel maps, and 3.2% and 1.8% for 0.5cm bixel maps. These differences are relatively small compared to the bixel intensity step size of 10%, making it relatively easy to assure that the correct intensity level was delivered to a bixel. Gross errors, such as an incorrect DMLC file or jaw setting, are easily detected by visual inspection or the resulting large mean and standard deviation values. **Conclusion:** This software tool facilitates accurate and expeditious IMRT delivery QA, allowing verification of all maps in a matter of minutes. The development of a more accurate convolution kernel will allow further reduction in comparison uncertainties. Clinical use will allow the establishment of a numerical threshold for a map to "pass" verification.

MO-D-224A-08

Automated Patient-Specific IMRT Quality Assurance Using Exit Detector Data

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Purpose: To develop tools for automatically evaluating IMRT treatments during delivery using exit detector data on a helical tomotherapy system. Methods and Materials: Treatment delivery sinograms and exit detector data were obtained following 6 treatment delivery sequences. The delivery sequences included 1.) No known error and nothing in the path of the beam, 2.) No known error with the couch in the path of the beam, 3.) No known error with an anthropomorphic pelvis phantom in the path of the beam, 4.) 1% error with nothing in the path of the beam, 5.) 1% error with the couch in the path of the beam, and 6.) 1% error with an anthropomorphic pelvis phantom in the path of the beam. A modeling technique was developed that could learn the attenuation relationships involved with the compressed data, thus distinguishing MLC errors from patient attenuation. A principal component modeling algorithm was developed for this purpose, employing the Hotellling's T^2 statistic and the Q statistic. To develop the principle component model, the sinogram data were standardized, subtracted from one another and projected onto the model. A prospective analysis was also performed using the MLC delivery sequence to produce an expected detector signal with and without errors. **Results:** The Q-statistic proved to be most useful for identifying errors in MLC openings, but correctly identified outliers and their contributing channel only when the model was trained with dissimilar (error-less and error containing) data sets. The T-statistic accounted for different attenuations present. **Conclusions:** Overall, the algorithms for analyzing compressed and uncompressed data proved to be useful in identifying errors as small as 1% in the MLC sequence.

MO-D-224A-09

Validation of Synchronized Dynamic Dose Reconstruction Using Film Dosimetry

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Purpose: To validate a method of retrospective dose reconstruction that uses real-time intra-treatment patient motion data that is synchronized with MLC leaf positions during IMRT treatments. **Method and Materials:** IMRT fields from an IRB-approved prostate protocol were delivered to a water-equivalent phantom on a programmable translation stage. Kodak XV film was placed at 5 cm depth with an SSD of 95cm and marked to register it with the Monte Carlo (MC) calculation grid. Motion was synchronized with beam delivery by using the target signal to trigger motion. Film measurements were repeated for each beam while the phantom was stationary, and while moving with both idealized and clinically measured motion profiles. MLC leaf positions and fluence state for each beam were obtained from the Varian DynaLog files. MC dose accumulation was performed which incorporated the real-time phantom motion, DynaLog files and beam state. Films were digitized and compared to the results of the MC calculations. **Results:** Film measurements in stationary phantoms were measured three times on two machines. The measured dose distributions were compared and showed an average difference of 0.38 +/- 1.53 cGy. The average difference between MC and film measurements of the moving phantom was 0.44 +/- 3.4 cGy and was independent of the motion profile. Measured dose patterns, for both stationary and moving phantoms, were generally well reproduced by MC dose accumulation, including tongue-and-groove and motion related features. Doses in moving and static phantoms were compared, for both films and simulations. The measured dose deviations due to motion were well-characterized by the MC dose accumulation method and not significantly different when a static phantom was compared to MC calculation. **Conclusion:** Real-time motion and machine data may be used to reconstruct the dose delivered to the target volume, and may serve as a basis for dynamic refinement of treatments.

Workshop Room 230 C
Display Evaluation Demonstration Workshop: Part I - Vendor Presentations

MO-D-230C-01
Evaluation of Medical Displays
E Samei*, Duke Univ, Durham, NC

Participants:
J Charette, Barcoview, LLC;
E Samei, Duke University;
N Hashimoto, Eizo Nanao;
K Compton, National Display Systems;
A Abileah, Planar Systems;
D Sorensen, Richardson Electronics / Image Systems;
C Lipfert, Scanditronix Wellhofer GmbH;
M Hasegawa, Totoku;
H Roehrig, University of Arizona

Electronic display is a key component of modern medicine, providing soft-copy viewing of medical images. Being the last component of the image chain, display quality can have a notable impact on overall accuracy and efficiency of the diagnostic process. Thus, it is necessary to ensure that the physical performance of a medical display is adequate for its intended use. Led by a task group initiative by the American Association of Physicists in Medicine (AAPM TG18), new guidelines have recently been published defining objective and standardized assessment procedures and criteria for acceptance testing and quality control of medical display devices (Samei et al, Med Phys 32:1205-25, 2005). The guidelines include detailed visual and quantitative methods and specific acceptance criteria for basic display characteristics including luminance, luminance spatial and angular response, resolution, noise, veiling glare, reflection, color uniformity, geometrical distortions, and display artifacts. The TG18 guidelines are also being gradually reflected in a number of other national and international directives including those by the IEC and the ACR. The goal of this demonstration workshop is multi-fold: 1) to present a tutorial on the TG18 guidelines and its adaptations, 2) to discuss its implementation by specific vendors, 3) to offer an opportunity for hands-on exposure to the practical aspects of display performance evaluation, 4) to provide an opportunity to informally interact with experts and ask questions, and 5) to offer a panel discussion on the issues about which there might be less consensus among experts. Representatives from the TG18 committee and from industry will be present to demonstrate and discuss display evaluation issues.

Part I
1:30-2:20 **Introduction**
Evaluation of Medical Displays, E Samei, Duke University
2:20-3:20 **Vendor lectures**
2:20-2:30 Compensation for ambient conditions, K Compton, National Display Systems
2:30-2:40 AAPM implementation using Barco software, J Charette, Barcoview, LLC
2:40-2:50 Quality Control Solutions based on AAPM TG18 from Eizo Nanao, N Hashimoto, Eizo Nanao Corp
2:50-3:00 The CFS (Calibration Feedback System) Toolkit, D Sorensen, Richardson Electronics
3:00-3:10 Totoku's Medical Display QA Solutions "i-model", M Hasegawa, Totoku Electric Co., Ltd.
3:10-3:20 The Priorities in the Medical Displays Parameters, A Abileah, Planar Systems

MO-D-230C-05
The CFS (Calibration Feedback System) Toolkit
D Sorenson*, Richardson Electronics

Medical imaging professionals know that properly calibrated displays are one key component to providing optimal image quality. CFS (Calibration Feedback System) provides software and hardware tools to enable this to be done properly and in a cost-effective manner. This includes addressing calibration of both monochrome and color displays on a hands-free basis, network monitoring and control, and access to TG18 patterns and methodology. An update of these tools will be provided.

MO-D-230C-06
Totoku's Medical Display QA Solutions "i-Model"
M Hasegawa*, Totoku Electric Co, Ueda Cty Nagano Pref, Japan

As PACS gains widespread use, the importance of quality assurance in medical image displays is rising and QA control methods are specified by guidelines and standards worldwide. In Japan, QA guidelines JESRA X-0093[-2005] kicked into full swing last August. The JESRA QA guidelines are based on the current AAPM-TG18 and the expected IEC standards.

In light of such trends in the market, TOTOKU developed a QA software that covers AAPM-TG18 and the other major standards, QA Medivisor. This software makes acceptance and constancy testing easy and accurate.

There is also a demand from medical personnel for a solution that quantitatively controls display quality. TOTOKU's i model displays satisfy such a need. The i-model displays have a luminance sensor that is installed in front of the LCD panel. It controls the display's luminance, the key factors in determining display quality, and realizes quick and easy evaluation of the display's conformance to the DICOM GSDF. This conformance evaluation function can be used to supplement other standards and guidelines.

Furthermore, TOTOKU's performance monitoring software PM Medivisor keeps a constant watch on operating status of all displays connected to the PACS network.

This workshop focuses on the basic QA procedures and a demonstration of the DICOM GSDF conformance evaluation on the i-model display.

Imaging Scientific Session 330A
Image Segmentation and Registration

MO-E-330A-01
Joint Estimation of Motion and Activity Concentration for 4D Gated PET Studies
F Qiao*[1], T Pan[2], J Clark[1], O Mawlawi[2], (1) Rice University, Houston, TX, (2) UT M.D. Anderson Cancer Center, Houston, TX

Purpose: Gated PET acquisition has been traditionally used to address the respiratory/cardiac motion induced artifacts. However, gated PET images usually have poor image quality due to insufficient photon counts. In this regard, various efforts have been made to estimate the motion information from the gated PET images first, and then use this information to produce motion-free, high quality images. The purpose of this study is to combine the two inter-related tasks—motion estimation and image reconstruction, into one single process. A potential advantage of such an approach is a more accurate estimation of the motion information, as well as a better quality of the reconstructed image. **Method and Materials:** Motion estimation and image reconstruction are jointly performed by maximizing a modified likelihood function that incorporates motion information. A computer simulation was performed on a 2D digital phantom placed in a simulated PET scanner to test the feasibility of this approach. The digital phantom consisted of a hot sphere moving sinusoidally within a warm background. The motion of the sphere was discretized into 10 steps. This simulated a tumor in the patient body influenced by the respiratory motion during a gated data acquisition using 10 time frames. The simulated PET scanner consisted of two parallel gamma cameras each having 140 detectors, and could rotate in 280 angular steps. Projection data were modeled to follow a Poisson statistics, with 20% of random counts. **Results:** The jointly estimated image recovered the shape of the moving object while still preserved a good image quality. Quantification error was reduced by 21.2% when compared to the static reconstruction, and SNR was improved by 185% when compared to the gated image. **Conclusion:** The joint estimation approach we have proposed has a good potential in motion artifacts correction for 4D PET images.

MO-E-330A-02

Automated Prostate Contour Drawing On Post-Implant CT Images Based On Ultrasound Volume and Seeds Positions

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Purpose: It is difficult to locate precisely the prostate on CT images. We propose an automated contouring help method based on data acquired during intra-operative brachytherapy procedure. The algorithm uses ultrasound volume and seeds positions to draw a preliminary contour on CT image.

Method and Materials: The data acquired during the clinical protocol are the intra-operative ultrasound volume and the seeds positions based on the detected needle insertion, and the seed positions and the CT images thirty days post-implant. In the first step the US volume and seed cloud are matched. For each z position of a clinical CT image, the US contour and seeds are extracted. The seeds positions are automatically detected on CT image and are used to calculate a transformation matrix to translate the seeds positions from day 0 to 30. The contours are reshaped using active contour. The reshaping process begins with the center slice and progress on both sides. The active contours are initialize with an expanded US volume. **Implementation (results):** There are no parameters to adjust in the first part of the algorithm. In the second part, there are six snakes parameters : continuity, curvature, convergence, gradient contraction minimum and contraction maximum. There is also a parameter controlling the resize factor of the US contours. The preliminary tests are conducted on ten clinical cases. Most of the contours were the final contour. The others needed a small physician action to correct the contours. **Conclusion:** This algorithm will be a useful tool to help physicians in tedious work to draw prostate contours on CT images. This automated approach presents the physician with intra-op US volume fused to the 30 days CT exams and proposes a new set of contours based on the morphology of the seed distribution.

MO-E-330A-03

Automated Texture Based CT Segmentation by Gabor Filtering and Fuzzy Clustering

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Purpose: To automate segmentation of lesion and organs at risk in lung patients by using Gabor filtering and fuzzy clustering for 4D CT image data and to check the usefulness of segmentation by using these methods. **Method and Materials:** Image was pre-processed with contrast enhancement and median filtering in order to prepare it for feature extraction. By filtering the enhanced image by Gabor filtering, texture features were extracted. Three fuzzy segmentation algorithms were selected including Fuzzy C-Means (FCM) , Gustaffson Kessel and Gath Geva (GG). Optimal number of clusters is determined by using validity criterion including Partition coefficient (F), Classification entropy (H), Xie Beni index (XB) and Partition index (SC). Images were then clustered and clusters visualized by using Principle Component Analysis (PCA). Finally, Performance of the algorithms was calculated by plotting the Receiver Operating Curves (ROC). **Results:** It was found that different clustering algorithms are best suited for different tissue/Organ segmentations. Furthermore, ROC curves indicated that FCM segmented the left lung with a True Positive (TP) rate of 94.72%, GK segmented Lesion with a TP rate of 88% and GG segmented heart with a TP rate of 74.8%. Fuzzy clustering methods in conjunction with Gabor filters are seen to completely outperform traditional Hard clustering methods like K-Means and K-Mediod. Finally, there is a marked difference seen between the fuzzy clustered regions and oncologist marked GTV. **Conclusion:** Texture based segmentation using Gabor filtering and fuzzy clustering perform quite well for Lesion and organs at risk segmentation, however, different fuzzy clustering methods should be combined for optimal segmentation. As Gabor filters use different frequencies and orientation for filtering, they reveal hidden structure, which may contribute to a more precise delineation of tissue/lesion structure.

MO-E-330A-04

Semi-Automatic Contouring for Respiratory Gating

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Purpose: Contouring is very labor intensive, especially in image-guided radiotherapy involving many image sets. To expedite this task, a semi-automatic image segmentation algorithm was developed to obtain lung and tumor volumes at the end-of-exhalation from contours drawn on an image set taken at the end-of-inhalation, and vice versa. **Method and Materials:** The gradient vector flow (GVF) algorithm was first proposed by Xu and Prince. This snake model can dynamically conform to object shapes in response to two kinds of forces: internal force from the contour itself, and external forces from image gradients. The energy cost function composed of these two forces can be minimized based on local GVF information. Different parameters were used for elasticity and rigidity of lung and tumor tissue. A variation of the GVF method is proposed to speed up the convergence. A momentum item $\xi \Delta U^t EXP(-t/T0)$ was added to the gradient vector calculation, in which ξ is a momentum constant and T_0 is the initial annealing temperature. **Results:** Two CT image sets were used to verify the algorithm. The lung and tumor contours drawn at one phase were used as an initial guess for the automatic drawing in the second phase. The GVF was calculated for each slice and some important parameters, like elasticity, rigidity and mass viscosity etc were assigned specific values for the optimization. The GVF calculation converged quickly to 10^{-3} in less than 5 seconds for a 512 x 512 image. The ratio of overlapping areas drawn by the algorithm to those of the manual approach exceeded 98%. **Conclusion:** The close match between computed and manually drawn contours, as well as the short computing time indicates the feasibility of this method for clinical use. This method should also be expandable to other applications like image guided radiotherapy. More work is needed for contouring 4D image sets.

MO-E-330A-05

Evaluation of Similarity Measures for Use in Intensity-Based Registration in Radiotherapy

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Purpose: In radiotherapy, the implementation of automated patient positioning depends on optimal selection of a similarity measure. Visual inspection of a registration is insufficient for evaluating performance of a measure, since high precision registration is usually involved. A general methodology is presented for evaluation of a measure based on convergence, precision and systematic errors for 2D and 3D imaging. **Method and Materials:** The following common metrics were studied: mean pixelwise product (PROD), normalized correlation coefficient (NCC), partitioned intensity uniformity (PIU), mutual information (MI), normalized mutual information (NMI), entropy of the difference image (ED), gradient correlation (GC), gradient difference (GD), and pattern intensity (PI). Imaging from an anthropomorphic phantom and clinical data were used. Portal images were acquired with a video camera EPID and a flat-panel imager. Kilovoltage digitally reconstructed radiographs (DRR) and megavoltage DRRs (MVDRR) were used for reference images. The following shifts were carried out: translations from -10 mm to +10 mm with 0.2 mm increments, and/or rotations from -10° to +10° with 0.2° increments. The effect down-sampling and image type were also investigated. **Results:** The selection of a measure depended on image type and down-sampling schedule. PROD introduced the largest systematic error. NCC, PIU, MI, NMI, and GD typically had systematic errors less than 1 mm and 1°. Down-sampling has less effect on NCC, PIU, and GC. MI, NMI, GC, GD, and PI have sharp "peaks" around their global optima. Asymmetry in the objective function was observed in NCC, PIU, MI, NMI, and ED. Registrations using GC, GD, and PI were less sensitive to the variation of anatomical structures. Using MVDRRs instead of DRRs increased objective function smoothness. **Conclusion:** A general methodology was presented for evaluation and selection of a measure.

Selection was application dependent, indicating necessity of a validation study, as presented here, prior to clinical use.

MO-E-330A-06

Cone Beam CT (CBCT) Image Fusion for Prostate Localization: Interobserver Variability Study Using Manual and Automatic Registration

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Purpose: Applying manual registration of CBCT to a reference image for prostate localization increases treatment time affecting prostate motion and patient setup. A reliable automatic registration can be more time efficient and accurate. This preliminary study demonstrates variability of manual fusion by multiple observers comparing manual to an in-house automatic fusion. Methods and Materials: 7 patients with 7 CBCT scans each were studied by 4 observers. Off-line manual fusion between CBCT and Simulation CT was performed using On-Board Imaging (OBI) software by *Varian version 1.2*. We pre-defined our Region of Interest (ROI) and Organ of Interest (OOI) to be the pelvic bones and the prostate respectively. Offsets were recorded in 4 degrees of freedom (3 translations and couch rotation). To increase precision, one outlier observation was excluded. Interobserver variation in manual registration was studied by determining percentage of observations that fall within 1 mm and 1 degree standard deviation (SD). Automatic registration, utilizing the uphill simplex, gradient correlation and mutual information similarity measures, was compared to the manual matched results using frequency histograms of the differences between the two methods. System robustness is checked using prostate calcifications. **Results:** Comparing different observers, 69% cranial-caudal (C-C), 83% anterior-posterior (A-P), 100% right-left (R-L), and 100% (couch rotation) of the observations fall within 1 mm,1 degree SD for ROI. 69% C-C, 75% A-P, 90% R-L, and 100% couch rotation were observed for OOI. ROI/OOI automatic fusion showed 92%/85% overall agreement with manual fusion within 2 mm respectively. **Conclusion:** Manual registration is time consuming and demonstrates observers' variations. The automatic method localizes the prostate within 15 seconds. More observers and measurements, methods utilizing drawn contours and implanted fiducial markers, will be required for system accuracy and precision. Our automatic registration with feed back from observers' experiences would enable on-line correction for prostate motion.

MO-E-330A-07

Knowledge-Based Auto-Contouring in 4D Radiation Therapy

M Chao*, E Schreibmann, T. Li, L. Xing, Stanford University, Stanford, CA

Purpose: In this work we develop a strategy of automatic contouring to relieve the effort of organ segmentation in 4D radiation therapy. The method adopts a novel technique of control volumes to achieve robust contour mapping among a series of 4D CT images. Methods and Materials: For a given patient, segmentation of tumor and sensitive structures was manually performed for one of the breathing phases by a physician. Along the segmented contours a number of small control volumes (~ 1cm) were selected. To obtain contours on another CT phase we mapped the control volumes collectively to this phase using rigid transformation, which served as a good starting contour for further adjustment. The final positions of mapped control volumes were determined by minimizing the energy function consisting of two terms: intensity similarity between the mapped volumes and the original volumes in the selected phase; elastic potential energy preventing control volumes from movement. The approach was tested with the 4D CT images of 5 lung cancer patients. **Results:** For the patients the knowledge-based approach of automatic contouring worked well even for CT images with significant deformations. In the lung case the contours have the average error of less than 2mm and a maximum error of 5mm for noisy anatomical structures. A significant reduction of time compared with manual contouring was achieved. **Conclusions:** The auto-mapping of contours in 4D radiation therapy was implemented with control volumes. The method provides an efficient way for 4D segmentation with high accuracy.

Imaging Symposium Room 330 D

Slice Wars: 64-Slice CT and Beyond

MO-E-330D-01

Overview of Recent Technology Developments in CT

J Hsieh*, GE Healthcare Technologies, Waukesha, WI

Cone Beam CT (CBCT) is one of the most recent technical advancements in x-ray computed tomography. The state-of-the-art 64-slice scanners provide isotropic sub-millimeter spatial resolution, significantly improved dose efficiency, large volumetric coverage, and markedly improved temporal resolution. These capabilities open doors to new clinical applications.

This presentation provides an overview of the recent technical advancements in CBCT. The discussion first covers technical challenges that face CBCT, such as detector complexity, electrical and mechanical design, image reconstruction algorithms, dose, and information management.

The second part discusses some of the recent developments in CBCT. These include the advanced dose-reduction techniques, the dual-source CT scanner, more advanced reconstruction algorithms that break the traditional noise vs. dose tradeoffs, larger volume coverage, and dual-energy CT for material decomposition and presentation. If the past 10 years of CT development can be characterized by the "slice-war", new technology developments are pointing to different directions.

Learning Objective:
1. Overview of the recent technology developments in CBCT.
2. Understand major technical challenges in CBCT development.
3. Explore future directions in CBCT technology.

MO-E-330D-02

256 Slice CT: Development, Design, and Clinical Applications

R Mather*[1], K Katada[2], M Okumura[3], T Rifu[3], (1) Toshiba America Medical Systems, (2) Fujita Health University, JP, (3) Toshiba Medical Systems Corporation, JP

As CT has evolved from axial to helical to multislice helical, the advanced applications have been focused on volumetric imaging. Improvements in coverage and temporal resolution have opened the doors to challenging imaging tasks such as coronary angiography. However, even with today's most advanced systems, there is still a several second time difference between the imaging of the superior and inferior portions of the heart. During this time period, small differences in heart rate and contrast medium can lead to discontinuities within the volume data as seen in some MPR images. Such artifacts can lead to inaccessibility or, worse, misdiagnosis. Toshiba has developed its 256 slice system to cover over 12 cm of anatomy in a single rotation with 0.5 mm slices to allow the complete coverage of the heart at a single, instantaneous time point. Such a system will enable seamless coverage free from banding artifacts and discontinuities. Furthermore, wide volume coverage will allow dynamic evaluation of the flow of contrast material and perfusion over an entire organ rather than in just 3-4 cm, opening the doors to new clinical applications. No new system is without technological challenges. The wide coverage of the 256 slice system requires a cone angle that is four times larger than a 64 slice system and advancements in cone beam reconstruction have been necessary to meet this need. This lecture will detail the design of Toshiba's 256 slice system and provide an overview of the system's image quality, dosimetry, and clinical applications. It will show early clinical examples of the advantages of whole organ coverage. It will explore some of the technological challenges inherent in such a system and the solutions to these challenges.

Educational Objectives
1. Understand the development and design of Toshiba's 256 slice system.
2. Understand the clinical utility of seamless, wide volume coverage
3. Understand the technical challenges of the 256
4. Understand the system's image quality

MO-E-330D-03

Clinical Perspective; Impact of Future Technology Developments; Cardiac CT; Challenges

M Vannier*, University of Chicago, Chicago, IL

Computed tomography is not the most frequent radiologic imaging procedure, but is arguably the most important in terms of clinical impact. CT is used extensively for emergencies, cardiovascular, pulmonary, gastrointestinal, endocrine, neurological, orthopedic and other applications - often as the first and only imaging procedure needed for diagnosis. The chances are very high that a patient will have a CT scan in the emergency department, as an outpatient or as an inpatient for a multitude of indications - pain, trauma, suspected infection or malignancy, and frequently to clarify or resolve a question raised by another abnormal test, such as an EKG abnormality or ultrasound finding. Despite the universality of CT in hospitals and clinics as well as free-standing imaging centers, the technology continues to evolve with greater coverage, faster acquisition and multienergy sources or detectors. The most demanding imaging applications are cardiovascular, where complex motion and small morphologic features coexist, so imaging methods that are very satisfactory elsewhere in the body may not be successful. Clinical cardiac CT consists of administering toxic materials, e.g., contrast media, while monitoring the EKG and illuminating the body with high brightness x-rays. Larger area detectors and higher frame acquisition rates are welcome improvements, but don't solve all of the problems encountered with variability due to respiratory, random body, and cardiac motion, especially in a spectrum of patients from infant to massively obese adult sizes (< 1 kg to 250 kg or more). The challenges and pitfalls in CT will be delineated and evaluated relative to current and future technology.

Joint Imaging/Therapy Symposium — Valencia B

Advances in Image-Guided Interventions

MO-E-ValB-01

Visualization of Anatomical Structures for Image Guided Surgery

E Grimson*, MIT, Cambridge, MA

Algorithmic methods from computer vision and machine learning are dramatically changing the practice of health care and the exploration of fundamental issues in neuroscience. By coupling knowledge of tissue response, atlases of normal anatomy, and statistical models of shape variation, these methods are used to build detailed, patient-specific reconstructions of neuroanatomical structure from MRI imagery. Such structural models can be automatically augmented with information about function (using fMRI), and about connectivity (using DT-MRI) to create detailed models of a patient's brain. These models are routinely used for surgical planning – how to reach the target tumor with minimal damage to nearby critical structures; and for surgical navigation – guiding the surgeon to the target site rapidly and safely.

By combining with statistical models of population variation, these methods can also be used to investigate basic neuroscience questions – how different are the shapes of subcortical structures between normal subjects and patients with a specific disease (such as schizophrenia or Alzheimer's); how do these shapes change with development in children, or with administration of pharmaceuticals; how do physiological properties differ between populations (such as the local structure of fiber orientation in white matter tracts). These computational methods provide a toolkit for exploring the structure and connectivity of neuroanatomical structures, in normal subjects and in diseased patients.

This lecture will review current methods for image segmentation and shape analysis.

Educational Objectives:
1. Understand algorithmic methods for image segmentation by tissue type;
2. Understand methods for analyzing shapes of anatomical structures across populations;
3. Understand the application of reconstructed anatomy for surgical guidance and navigation.

MO-E-ValB-02

Hybrid Imaging for Guidance of Interventional Procedures

R Fahrig*, Department of Radiology, Stanford University, Stanford, CA

The last decade has seen an explosion in the number of procedures carried out using minimally invasive approaches, as devices and techniques develop. The promise of these new procedures is realized only with a parallel improvement in imaging techniques. Hybrid systems that combine real-time acquisition with cross-sectional and/or functional data are one response to the need, and several such systems have now reached the clinic. Depending on the application, different combinations can be used to greater advantage. The interventionalist's familiarity with x-ray fluoroscopy and the real-time and projection capability makes it a logical first choice to marry with others such as ultrasound, CT or MR.

The combination of fluoroscopy with C-arm CT for application to 3D vascular imaging was first implemented in the mid-90's. New flat-panel detector technology is now expanding the role of C-arm CT into low-contrast imaging applications such as detection of fresh bleeds during treatment of intracranial abnormalities and guidance of vascular and percutaneous abdominal interventions. Highest image quality depends on correction algorithms for lag, truncation, scatter etc. all of which are still under investigation. Recent investigations indicate that contrast resolution as low as 5 HU is possible under clinically realistic conditions.

The combination of fluoroscopy with MR has also been under investigation since the mid-90's with several prototype long-travel systems installed in research clinics. While feasibility of such systems has been shown, patient transport between imaging FOVs has been complicated and enthusiasm for the systems has been limited. New flat-panel detectors which are immune to static magnetic fields, and new x-ray tube designs are now under development that allow close integration of fluoroscopy and MR systems. Using a double-donut interventional magnet and a static-anode x-ray tube, good image quality can be achieved from both modalities if care is taken to maintain magnetic field homogeneity, rf noise is limited, and the electron optics of the x-ray tube are controlled. Switching between modalities can take a little as one minute.

The current status of X-ray/MR, and of X-ray/CT and C-arm fluoroscopy/C-arm CT will be discussed and described. New hardware and software for X-ray/MR and new image correction and visualization algorithms for fluoroscopy/C-arm CT will be described. Current challenges in the area will be outlined.

Educational Objectives:
1. Understand the options available for hybrid interventional guidance.
2. Understand the issues related to image quality in C-arm-based CT and XMR
3. Understand the current challenges relating to clinical workflow, multi-modality registration and image visualization

Disclosure:
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MO-E-ValB-03

MRI-Guided Focused Ultrasound

K Hynynen*, University of Toronto, Sunnybrook Health Sciences Centre, Toronto, Ontario, CA

Magnetic Resonance Imaging (MRI) provides such features as excellent soft tissue contrast, temperature sensitivity and ability to detect thermally coagulated tissue, that make it well suited for the guidance, control, and monitoring of thermal therapies. In this talk the current progress in MRI guided focused ultrasound thermal ablations and other non thermal interventions will be reviewed. The treatment of uterine fibroids has been approved by the FDA and is on its way to become routine. There are several other clinical trials in testing MRI guided focused ultrasound for the treatment of breast and other tumors. In addition, there is evidence that low thermal exposures controlled by MRI can be used to locally activate treatments. Finally, animal experiments show that ultrasound exposures

can induce transient blood-brain barrier disruption thus allowing targeted delivery of molecules such as chemotherapeutic agents in the brain.

Professional Symposium Room 230A
Intellectual Property

MO-E-230A-01
Legal Issues
M Davis*, Varian Medical Systems, Houston, TX

Research plays a prime role in the professional lives of many medical physicists, especially those in academic institutions. The prime goal of this research is to acquire new knowledge. Acquiring the knowledge, however, is not sufficient, in that the information must also be disseminated to the community.
The standard vehicle for dissemination of research knowledge is the peer-reviewed journal. In fact, a medical physicist's academic advancement is often based on the number of papers that have appeared in a peer-reviewed journal. However, publication in a journal introduces significant restriction on the ability for subsequent dissemination of the research information. Prior to publication, the producer of the information is the complete owner of the information. Researchers may disseminate the information to anyone they please in any form they please. Publication, however, places significant limitations as to how information may be disseminated because of the existence of copyright laws. Often, the individual who has generated the information has turned over ownership of the information to the publisher of the journal and no longer has complete control over how the information may be distributed to others.
Limits exist, however, on the extent that a publisher may control dissemination of the information in a journal article. In the distant past (>40 yr ago) the publisher exercised significant control over dissemination. If an author wished to provide others with copies of a paper, the author would have to purchase reprints of the article from the publisher and deliver the reprint to the recipient. In the more recent past, the author of the article, or anyone else for that matter, may photocopy the article from the journal. The ease of photocopying has established some principles of "fair use," that is, scenarios where photocopying lies within the limitations of copyright restrictions, and other scenarios where photocopying violates copyright. For example, individuals may copy an article from a journal for their own use, but to make a large number of copies without permission for distribution to a class may violate copyright restrictions. Presently, most journal articles appear in electronic form, typically as a PDF file that can be downloaded and stored on an individual's computer. The same file can be emailed to many recipients. Because of the ease of dissemination of this information, a new paradigm for dissemination is necessary. It is necessary to balance the need to disseminate information against the need for the journal to recoup the expenses of publication and dissemination and, when appropriate, make sufficient profit to warrant remaining in business.

MO-E-230A-02
Intellectual Property - Medical Physics
W Hendee*, Medical College of Wisconsin, Milwaukee, WI

Every medically-oriented scientific journal is confronted with a fundamental conflict. The journal exists for the purpose of disseminating information produced by authors to others who may be able to use the information to enhance their own research, education programs or clinical practices. Journals and the information they disseminate contribute in a substantial way to progress in science, education and the clinical practice of medicine. Articles published in a legitimate scientific journal have high credibility because they are from identified authors, are peer-reviewed, and are integrated within the literature related to the topics of the articles. The conflict in this process arises because articles contain information that belongs to the authors and the authors' institutions, and may represent intellectual property that will ultimately be marketed commercially. The journal has an obligation to protect this property and its potential value to the authors and institutions. This protection is provided by the journal's copyright over the information. When this protection is compromised by plagiarism of the article's information by another author, the journal must be prepared to act through enactment of a plagiarism policy approved, in the case of Medical Physics, by the journal's Board of Editors and by the sponsoring society (American Association of Physicists in Medicine). It is possible for authors to plagiarize their own work, through duplicate publication in more than one journal. For this purpose, Medical Physics requires submission of a Conflict of Interest statement that includes disclosure of an article's publication elsewhere before submission to Medical Physics.

MO-E-230A-03
Journal of Applied Clinical Medical Physics
M Mills*, James Graham Brown Cancer Center, Louisville, KY

Publication, or dissemination of knowledge, is an essential component of scholarly activity. However, the money and profit associated with access to scholarly information is the source of both a crisis and a revolution to address that crisis. It is most common for the author to lose ownership, copyright, other property rights and control over the information. Unfortunately, these problems are not recognized as public policy issues. Public policy is important because access to print journal information has traditionally been through publicly funded libraries, and libraries are in a long, downward crisis. Universities pay scholars, usually through income derived from governmental grants, grants from non-profit and for-profit corporations, tuition, fund-raising, corporate participation, etc. The majority of funding for scholarly activities comes from public sources. Scholars produce scholarly articles, and then universities pay for their libraries and scholars to have access to these scholarly articles. When scholars give up copyright to creative work, they have no say about how their research is disseminated and priced. The Journal of Applied Clinical Medical Physics is part of the open-source publication revolution. The author retains the copyright and retains full control over the dissemination of the scholarly contribution. The key for the JACMP was to lower transaction and production costs by a factor of four below the cost of providing a subscription-based print journal with restricted online access. The JACMP is squarely in the middle of the open-source publication revolution as it offers scholarly articles to the worldwide medical physics community without cost.

Objectives: 1. Understand the history and importance of the open-source publication revolution. 2. Understand the role of the JACMP in the dissemination of scholarly activity to the worldwide medical physics community

Therapy Continuing Education Course Valencia A
CE: IMRT Site Specific - I: Prostate, GYN, Pelvis

MO-E-ValA-01
Role of IMRT in the Treatment of Gynecologic Malignancies
J Roeske*, University of Chicago, Chicago, IL

Intensity modulated radiation therapy (IMRT) is increasingly used for the treatment of gynecologic malignancies. A survey conducted in 2004 found that over 35% of the radiation oncology clinics with IMRT were using this modality in gynecologic patients. While treatment planning is an important aspect of gynecologic IMRT, successful implementation requires careful attention to detail throughout the entire planning process. At the University of Chicago, IMRT planning for whole-pelvic gynecologic patients begins with a CT simulation. Patients are treated in the supine position, and customized immobilization devices (alpha cradles) are fabricated which are subsequently indexed to the treatment table. Oral, intravenous and rectal contrast are used to aid in the delineation of the CTV and surrounding normal tissues. The CTV consists of the contrast enhanced vessels (plus a 2 cm margin) to identify common, external and internal nodal regions along with the upper half of the vagina, parametrial tissues, presacral region and uterus (if present). A PTV is added to the CTV based on measured set-up uncertainties and organ motion data. Normal tissues that are contoured include the bladder, rectum, small bowel and pelvic bone marrow. For treatment planning, 7 (small patients) or 9 (larger patients) equally spaced, co-planar beams are used. Input parameters derived for treatment planning were developed over time, and their evolution will be discussed. Values used for a number of commercially available planning systems will also be presented. Treatment plans are evaluated primarily based on the PTV coverage and normal tissue DVHs. For the PTV, acceptable plans are defined as those which cover >98% of the volume with the prescription dose while <2% of the PTV receives >110% of the prescription dose.

Evaluation of small bowel is based on a normal tissue complication probability (NTCP) curve for the incidence of acute gastrointestinal toxicity of IMRT patients treated in our clinic. From this analysis, acceptable plans are those in which <200 cc of the small bowel region receives 45 Gy (prescription dose). We have also recently defined bone marrow constraints for patients receiving concomitant chemotherapy, and these will be discussed. Image-guided radiotherapy (IGRT) has received increasing attention as a component of treatment delivery. In gynecologic IMRT, there are three areas where IGRT may offer substantial benefit. First, IGRT may reduce geometric misses by providing daily information on isocenter displacements and patient rotations. Additionally, IGRT has an important role in cervical cancer patients where the tumor is shrinking during the course of treatment. Using IGRT, tumor size and position can be monitored and the treatment plan can be modified appropriately. Lastly, IGRT approaches are currently being considered in the development of IMRT approaches to replace intracavitary brachytherapy. Clinical examples of each of these approaches will be presented.

Educational Objectives:
1. To understand the practical aspects of IMRT planning for gynecologic malignancies
2. To describe the criteria for IMRT plan evaluation in gynecologic patients
3. To consider the role of image-guided technologies in this disease site

MO-E-ValA-02

IMRT for Prostate Cancer

R Price*, Fox Chase Cancer Center, Philadelphia, PA

Treatment of prostate cancer with IMRT requires great care in order to achieve the intended results. The prostate is a mobile structure compared to the surrounding bony anatomy. Daily setup, immobilization and localization uncertainties can be addressed by increasing the PTV but results in additional dose to surrounding normal structures. At FCCC we attempt to reduce the uncertainty by employing daily localization using BAT ultrasound or implanted fiducials and currently use an 8mm growth in all directions except posteriorly where 5mm is typical. Patients with fiducials and those being irradiated in the post-prostatectomy setting undergo localization via an in-room CT scanner. These methods allow for minimal PTV expansion by moving the prostate or prostate bed into the intended dose region.
All patients are simulated and treated supine without a thermoplastic immobilizer to minimize respiratory related prostatic motion and to facilitate the use of ultrasound. Patients undergo CT followed immediately by MR simulations with the rectum empty. These data are fused and all soft tissue structures contoured based on MR. We believe the apex of the prostate is more accurately visualized with MR without the potential prostate distortion associated with a retrograde urethrogram. Dose limiting structures primarily include the rectum, bladder, and femoral heads, but may also include bowel and erectile tissues. The delivery of high doses (70-80+Gy) using 3D CRT invariably includes rectal shielding to some degree in order to avoid unwanted complications. Rectal shielding also creates a dose gradient across the posterior prostate. Our initial comparisons at 78Gy between 3D CRT and IMRT resulted in an increase in 95% PTV coverage from approximately 76Gy to 78Gy, respectively and a reduction of approximately 6Gy to the "hottest" 20% of the rectum. We have developed "plan acceptance criteria" based on published data with respect to rectal complications. DVH analysis is used to ensure that the rectal volumes receiving 65Gy and 40Gy are less than 17% and 35%, respectively. Additionally, the bladder volumes receiving 65Gy and 40Gy are less than 25% and 50%, respectively. The volume of either femoral head receiving 50Gy should be less than 10%. PTV coverage should result in at least 95% of the volume receiving the prescription dose. It should be noted that the 3D dose distribution itself plays an important role in IMRT delivery and DVH analysis alone may not be sufficient. The isodose distribution should be such that the 50% and 90% lines do not traverse the full or half width of the rectum on any CT slice, respectively. Additionally, emphasis is given to treatment time not only for throughput but also for patient comfort. Quality assurance includes verification of absolute dose as well as the resultant spatial distribution and our plan acceptance is based on ±3% and 3mm DTA, respectively. We have been able to meet the absolute dose criteria in approximately 94% of cases.

Educational Objectives:
1. To understand the practical steps associated with IMRT of the prostate
2. To understand the planning methods utilized to achieve the numerical values presented for plan acceptance

Therapy Scientific Session Room 224 C

Teletherapy Planning and Delivery I

MO-E-224C-01

Quantitative Evaluation of Conformal Treatment Plans: A New Methodology

J Menhel*, D Levin, D Alezra, Z Symon, R Pfeffer, Sheba Medical Center, Tel-Hashomer, JP, Sheba Medical Center, Tel-Hashomer, IL, Sheba Medical Center, Ramat Gan, IL

Purpose: To establish a quantitative method for evaluation of 3D conformal and IMRT plans based on organ specific tolerances and target coverage assessment. **Method and Materials:** We propose a novel evaluation criterion, which reflects both target coverage and overdoses in organs at risk (OARs). Critical Organ Scoring Index (COSI) is defined as: $COSI = 1 - (V_{>tol} / TC)$, where $V_{>tol}$ is the volume of OAR receiving more than tolerance dose and TC is the partial volume of target receiving at least prescription dose. To assess overall plan conformity we propose a 2D graphical representation of COSI vs. Conformity Index (CI). This method enables quantitative evaluation of competing plans in terms of multiple organs at risk. The COSI-CI plots were tested for evaluation of the following treatment sites: maxillary sinus and pancreatic tumors, to compare non-coplanar 3D and IMRT plans, and cavernous sinus meningiomas for stereotactic radiation with either dynamic arcs or IMRT. **Results:** For all three sites COSI-CI plots assisted the physician in choosing the optimal plan, in terms of both target coverage and critical organ sparing. We verified each choice by analyzing individual DVHs and isodose distributions. Comparing our index to the widely used Conformation Number, we found that in all cases where there were discrepancies between CN and COSI in the choice of optimal treatment plan, the COSI-CI graphs led to the better plan.**Conclusion:** We introduced a novel scoring index, COSI, which is a measure of both target coverage and critical organ overdose. Using the COSI index, we propose a two-dimensional representation of plan quality for comparison purposes. The method was found it to be a quick and reliable tool in aiding physicians in the choice of correct plans. The main advantage of the proposed methodology is its ability to simultaneously compare multiple plans as well as multiple critical structures.

MO-E-224C-02

Quantification of Respiration-Induced Dosimetric Impact On Liver for Abdominal Radiotherapy

L Lin [1, 2], C Shi [1, 2], B Salter[3], M Fuss [2], N Papanikolaou[1, 2],
(1) University of Texas health Science Center, San antonio, TX, (2) Cancer Therapy and Research Center, San Antonio, TX, (3) University of Utah Huntsman Cancer Institute, Salt Lake City, UT

Purpose: To quantify the dosimetric impact of respiratory motion on liver dose for IMRT abdominal radiotherapy based on 4D CT imaging **Method and Materials:** 4D-CT images of a patient with klatskin tumor were acquired on a GE CT scanner during free-breathing. Respiratory information was recorded using the Varian RPM system. The images were sorted retrospectively into ten respiratory phases. For each phase-binned 4D data set, manual contours for liver were delineated. The Corvus inverse planning system (NOMOS Inc.) was used to generate optimized treatment plans. Two kinds of image registration methods, feature-based iterative closest point (ICP) rigid image registration and normalized mutual information (NMI) non-rigid image registration method, were implemented to transform each of the ten phases to a reference phase. The reference phase was the end of expiration (50%phase). A composite 4D-DVH, which accounts for respiratory induced voxel motion, was subsequently calculated using equal weighting for each respiratory phase. A dose of 45Gy to the target was prescribed. The treatment plan was optimized to provide a minimum of 95% isodose coverage for PTV. **Results:** Variation of liver dose throughout each of the 10 calculated phases was within 5%. 4D

effective DVH showed reduced volume coverage up to 18% for the same dose. In the high dose region of the liver DVH, the dose was less for the NMI algorithm as compared to the ICP algorithm. **Conclusions:** Two kinds of image registration methods have been implemented to derive 4D effective DVHs for an abdominal patient. In this study we found that respiratory-induced motion does not produce a significant alteration of the liver DVH between the 10 phases. However, the 4D effective DVH method shows that the liver received less dose.

MO-E-224C-03

A 3D Collision Avoidance Tool for External Beam Radiation Therapy Treatment Planning

F Hamza-Lup*[1], L Davis[2], S Meeks[3], O Zeidan[3], (1) Armstrong Atlantic State University, Savannah, GA, (2) Tirrion Technologies LLC, Orlando, Fl, (3) M. D. Anderson Cancer Center Orlando

Purpose: We are presenting the design and implementation of a 3D-graphical tool for the detection of potential collisions of various linac components for patient-specific external treatment planning **Method and Materials:** The graphical tool uses the Virtual Reality Modeling Language (VRML) to model the exact geometry of any treatment machine by reading its manufacturer's CAD design files. The robust system is based on VRML and Java programming that allows for accurate simulation of any linac hardware module based on the manufacturer's CAD drawings. **Results:** The tool predicted eminent collisions between different linac components graphically for a simulated Varian 2100EX for certain gantry and table angles. The collision angles were verified manually on the linac and found to agree with the predicted angles from the tool. **Conclusions:** We have developed a 3D graphical simulation tool that can be used as a stand alone application to assist in external treatment planning by visually simulating collisions between various linac hardware components. Unlike other anti-collision methods developed so far in the literature, our tool would be able to model the details of the treatment linac and add-on devices for patient-specific setups. Hence, the tool will create patient-specific realistic collision maps for any external treatment scenario. The tool can be used as a stand-alone program and it is platform independent.

MO-E-224C-04

Motorized Multi-Leaf Collimator for Electrons: Measurements with a Prototype and Monte Carlo Simulations

H Tremblay*, H Bouchard, S Mercure, J Robichaud, M Beausoleil, M Charette, J Carrier, Hopital Notre-Dame du CHUM, Montreal, Quebec, CA

Purpose: To develop a motorized multi-leaf collimator for electrons (eMLC) and to compare preliminary measurements to Monte Carlo simulations. **Method and Materials:** An eMLC has been developed. It is the first prototype with fully motorized capabilities. The eMLC is remotely controlled by the operator using home brewed and fully graphical software running on a Windows workstation. The control workstation is connected to the eMLC's custom-built electronic controller which keeps track of the component states and executes various low-level commands, including leaf displacement orders. There are 36 independent brass leaves on each side of the eMLC and the maximum size of the generated field is 25.2 X 19.5 cm^2. The interleaf distance is less than 0.03 mm. The eMLC prototype is an add-on device for the Elekta Precise linac (Elekta Ltd., England). The actual distance from the source to the bottom of the leaves is 95.3 cm. The eMLC has been modeled using the BEAMnrc Monte Carlo toolkit and every possible leaf positions is reproducible with our Monte Carlo model. **Results:** Various preliminary measurements were performed: open field, closed field, one leaf profile, interleaf leakage, leaf transmission, and comparison with conventional custom cutouts. For all measurements, comparison to Monte Carlo simulations are carried out. The transmission through the leaves is 2.4% for a 12 MeV field at the surface of a water phantom with SSD=100 cm. The interleaf leakage is negligible as no interleaf pattern is detected on a closed field profile for all the investigated energies (up to 12 MeV). **Conclusion:** The motorized eMLC prototype is versatile and easy to operate with a computer control from outside the treatment room. Possible applications of the eMLC go from simply replacing the conventional custom cutouts to complex usages like MERT or electron arc therapy.

Research sponsored by Elekta Ltd.

MO-E-224C-05

Comparison of TomoTherapy with Conventional Electron/X-Ray Treatment Plans for Chest Wall

M Ashenafi*, R Boyd, K Lo, T Lee, K Hogstrom, Mary Bird Perkins Cancer Center, Baton Rouge, LA, Louisiana State University, Baton Rouge, LA

Purpose: Post-mastectomy radiotherapy (PMRT) of the chest wall (CW) often will involve use of electron beams due to their rapid fall-off of dose near the practical range of the electron energy. The TomoTherapy helical, fan-beam delivery system, along with the inverse-planning optimizer, has the potential to provide planning and delivery of 6 MV x-rays to superficial target volumes conventionally treated with electrons. In the present study, five chest wall patients were planned for TomoTherapy and compared to their conventional plan that utilized electron beams. Analysis of breathing motion were not included. Methods and Materials: Five PMRT patients treated with electron beams and planned on the Pinnacle treatment planning system (TPS) were selected. A planning target volume (PTV) was generated to follow the isodose contour defined by 90% of the prescribed dose on the Pinnacle plan. Target dose homogeneity in the Tomotherapy TPS dose optimizer was relaxed to better achieve critical structure dose objectives when necessary. Normal tissue complication probabilities (NTCP) were calculated for the lung and the heart. A questionnaire form was provided for the radiation oncologist to evaluate each plan. **Results:** For all cases, the TomoTherapy plan was rated superior to the Pinnacle plan by the radiation oncologists. The TomoTherapy TPS produced a significantly more uniform dose distribution in the PTV. The average volume of ipsilateral lung receiving dose above 20 Gy was reduced from 21.5% to 17.7%. The average volume of heart receiving dose above 30 Gy was reduced from 2.2% to 1.3%. NTCP for the lung and heart were also reduced in the TomoTherapy plan. **Conclusion:** The results of this study demonstrated that TomoTherapy is able to deliver clinically-acceptable dose distributions to a "static" model of PMRT patients conventionally treated with electron beams.

Supported in part by a research agreement with TomoTherapy, Inc.

MO-E-224C-06

Improving Homogeneity of Abutment Dosimetry in Segmented-Field Electron Conformal Therapy Using Variable Insert Positioning

J Richert*[1], K Hogstrom[1, 2], R Boyd[1, 2], (1) Louisiana State University, Baton Rouge, LA, (2) Mary Bird Perkins Cancer Center, Baton Rouge, LA

Purpose: To improve dose homogeneity in segmented-field electron conformal therapy by matching penumbra of abutted fields. **Method and Materials:** A Varian 21EX electron applicator was modified to allow for energy-dependent positioning of Cerrobend inserts resulting in energy-dependent air gaps. Air gaps were chosen based on theoretical calculations to approximately match penumbra for 6, 9, 12, 16, and 20 MeV beams at 1.5-cm depth in a water phantom at 100-cm SSD. Treatment plans developed for four simulated target volumes using the modified applicator were compared to identical plans using the standard applicator. Improvement in dose homogeneity was assessed by comparing maximum and minimum dose, mean dose, and sigma of the dose distribution in the target volume for the two plans. Subsequently, electron blocks were cut with diverging edges using the Compu•cutter® system, and dose plans using the modified applicator were delivered to Kodak XV film in a polystyrene phantom to demonstrate feasibility. **Results:** Treatment planning results using the modified applicator showed improved dose homogeneity in all four simulated target volumes as compared to plans using the standard applicator. Averaged for all four PTVs; dose spread (D_{max} - D_{min}) decreased by 35%, σ of the dose distribution decreased by 29%, and $D_{90\text{-}10}$ decreased by 31%. Dose delivered to a film phantom using the modified applicator was found to agree well with predictions (within approximately 5%) of the Pinnacle treatment planning system in the abutment region of the PTV ($\pm$2 cm from the abutment edge at depths $\geq$ 1.5 cm). **Conclusion:** The results of this study suggest segmented-field electron conformal therapy can be delivered with significant improvement in dose homogeneity as compared to the current method by using energy-dependent positioning of electron inserts to match beam penumbra.

MO-E-224C-07

Time-Resolved 4D Dynamic Arc Therapy

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Purpose: To develop a 4D dynamic arc therapy with the capability of MLC-shaped irradiation field tracking for moving tumor targets. **Method and Materials:** 4D CT images at 10 different breathing phases were acquired and transferred to a treatment planning system. The tumor target was contoured and a 3D conformal arc therapy (3DCAT) plan was generated for each phase. For each 3DCAT plan, the selected control points (gantry angles) and the MLC-defined conformal apertures were correlated to the patient's respiration phases. A program was developed to obtain a 4D DMLC leaf sequence with the capability of tracking the target motion based on the ten 3DCAT DMLC leaf sequence files. To evaluate the 4D plan, a deformable registration was adopted to combine dose distributions and DVHs and the results were compared with those obtained using the conventional 3D and gating plans. Five lung cancer cases and film measurements embedded in a moving phantom were used to investigate the feasibility of the proposed technique. **Results:** An efficient 4D dynamic arc therapy was implemented. Experimental measurements indicated that the dose distribution in the moving target delivered using the proposed technique is equivalent to that in a static target delivered using a conventional 3D arc therapy. Compared with the 3D plans, the target received more conformal doses and the sensitive structures, especially the lung, were better spared in the 4D plans for all the test cases. The treatment time for the 4D plan is comparable to the 3DCAT plan, much more efficient than the gating treatment.**Conclusion:** It is feasible to incorporate the intra-fraction organ motion into a 4D dynamic arc treatment planning to track the moving targets. Compared with conventional treatment strategies, this technique has great potentials to provide more conformal dose distribution and better sensitive structure sparing with extremely high efficiency.

Therapy Symposium — Room 224 A

Stereotactic Body Radiotherapy

MO-E-224A-01

Stereotactic Body Radiation Therapy: (1) Clinical Outcomes Following SBRT IGRT

L Dawson*, Princess Margaret Hospital, University Health Network, University of Toronto, Toronto, Ontario, CA

Advances in high precision radiation planning and delivery, image guidance technologies and methods to account for and reduce organ motion have made it possible for cranial stereotactic radiosurgery techniques to be applied to tumors outside of the brain. Stereotactic body radiation therapy (SBRT) refers to the use of a limited number of high dose fractions delivered very conformally to targets with high accuracy, using biologic doses of radiation far higher than those used in standard fractionation.

The rationale for SBRT is that there is a need for improved local therapies for many primary cancers and also in the situation when there are 'oligo' (i.e. isolated) metastases, specifically in sites where surgery has been shown previously to be able to cure patients with 'oligo' metastases, e.g. colorectal cancer, renal cell cancer and sarcoma. SBRT has the potential to be used in place of surgery in situations when surgery may associated with high risk.

Advancements outside of radiation oncology also provide rationale for SBRT. Functional imaging such as PET allows better patient selection for SBRT. Furthermore, improvements in systemic therapy more likely to control micro-metastases provide rationale for improving local therapies, such as SBRT, to reduce large foci of tumor burden.

There are radiobiological advantages to SBRT including less opportunity for tumor repopulation and repair. Furthermore, the shorter SBRT treatment times are more convenient for patients and have resource utilization advantages.

With highly potent doses of SBRT delivered with steep dose gradients, the potential for geometric uncertainties in the setting of SBRT to lead to adverse clinical outcomes (tumor recurrence and/or toxicity) is high. Thus, the need for image guided radiation therapy (IGRT) to improve precision of dose delivered is heightened. IGRT decreases the heterogeneity in delivered doses, improving our ability to measure the impact of dosimetric and non-dosimetric factors on SBRT clinical outcomes.

This lecture will provide an overview of the rapidly increasing clinical experience with SBRT and IGRT in the setting of SBRT. Case examples demonstrating clinical benefits and potential toxicities will be discussed.

Educational Objectives:
1. To understand the clinical rationale for SBRT
2. To describe the rationale for IGRT in SBRT
3. To understand the increased risks of SBRT compared to conventional RT and the increased potential for error

MO-E-224A-02

Stereotactic Body Radiation Therapy: (1) Highlights of the AAPM Task Group Report 101 On SBRT

S Benedict*, VA Commonwealth Univ, Richmond, VA

The approved charges for the AAPM Task Group 101 entitled, "Stereotactic Body Radiation Therapy", include: Charge (1): To review the literature and identify the range of historical experiences, reported clinical findings and expected outcomes; Charge (2): To review the relevant commercial products and associated clinical findings for an assessment of system capabilities, technology limitations, and patient related expectations and outcomes; Charge (3): Determine required criteria for setting-up and establishing an ESRT facility, including protocols, equipment, resources, and QA procedures; Charge (4): Develop consistent documentation for prescribing, reporting, and recording ESRT treatment delivery. This part of the presentation will include highlights from the current TG101 report currently under review, including strategies and requirements for patient immobilization and repositioning, respiratory management, treatment planning, and reporting.

MO-E-224A-03

Stereotactic Body Radiation Therapy: (3) Clinical Experience at MSKCC

D Lovelock*, Mem Sloan-Kettering Cancer Ctr, New York, NY

Stereotactic Body Radiotherapy (SBRT) - Clinical Experience from MSKCC SBRT has the potential to maximize the benefit of highly conformal dose delivery. New imaging capabilities and the improved precision of treatment machines is making possible the delivery of high doses to targets while minimizing dose to normal tissue and sparing nearby critical structures. As a result, new clinical techniques are being established to treat disease in soft tissue, such as metastatic disease in liver, lung, and lymph nodes and also to deliver very high doses to bony targets such as the spine. Both hypo-fractionated and single fraction strategies are used.

The clinical procedures used to treat these sites at Memorial Sloan-Kettering Cancer Center will be described, along with some preliminary outcomes.

Workshop — Room 230 C

Display Evaluation Demonstration Workshop: Part II - Overview/Hands On Demonstrations

MO-E-230C-00

Display Evaluation Demonstration Workshop: Part II

E Samei*, Duke Univ, Durham, NC

Participants:
J Charette, Barcoview, LLC;
E Samei, Duke University;
N Hashimoto, Eizo Nanao;
K Compton, National Display Systems;

A Abileah, Planar Systems;
D Sorensen, Richardson Electronics / Image Systems;
C Lipfert, Scanditronix Wellhofer GmbH;
M Hasegawa, Totoku;
H Roehrig, University of Arizona
GmbH; M Hasegawa, Totoku; H Roehrig, University of Arizona

Electronic display is a key component of modern medicine, providing soft-copy viewing of medical images. Being the last component of the image chain, display quality can have a notable impact on overall accuracy and efficiency of the diagnostic process. Thus, it is necessary to ensure that the physical performance of a medical display is adequate for its intended use. Led by a task group initiative by the American Association of Physicists in Medicine (AAPM TG18), new guidelines have recently been published defining objective and standardized assessment procedures and criteria for acceptance testing and quality control of medical display devices (Samei et al, Med Phys 32:1205-25, 2005). The guidelines include detailed visual and quantitative methods and specific acceptance criteria for basic display characteristics including luminance, luminance spatial and angular response, resolution, noise, veiling glare, reflection, color uniformity, geometrical distortions, and display artifacts. The TG18 guidelines are also being gradually reflected in a number of other national and international directives including those by the IEC and the ACR. The goal of this demonstration workshop is multi-fold: 1) to present a tutorial on the TG18 guidelines and its adaptations, 2) to discuss its implementation by specific vendors, 3) to offer an opportunity for hands-on exposure to the practical aspects of display performance evaluation, 4) to provide an opportunity to informally interact with experts and ask questions, and 5) to offer a panel discussion on the issues about which there might be less consensus among experts. Representatives from the TG18 committee and from industry will be present to demonstrate and discuss display evaluation issues.

Part II:

4:00-4:10 Local and Remote QA/QC for Color Monitors, H Roehrig, Univ of Arizona
4:10-4:20 QA Luminance Measurements at Medical Displays using a Flexible Spot Luminance Meter, C Lipfert, Scanditronix Wellhofer GmbH
4:20-5:10 Hands-on demonstration:
5:10-5:30 Plenary Q&A and panel discussion

MO-E-230C-01

Local and Remote QA/QC for Color Monitors

H Roehrig*, Dept. Radiology and College of Optical Sciences, University of Arizona, Radiology Research Lab, Tucson, AZ

The adoption of digital detectors and PACS has provided physicians in healthcare institutions with an effective means to electronically generate, transmit, archive, retrieve and display images to be used for the diagnosis of disease. Monochrome CRTs and LCDs were the original choice of displays. Now color displays are increasingly replacing monochrome displays mainly for cost reasons in Radiology, but also for use in multi-modality display stations and in areas where color is essential such as in Telemedicine and Telepathology.

The ACR-NEMA Working Group 11 has developed a Display Function Standard to allow for the standardization of monochrome image display devices. The AAPM Task Group 18 has developed methods to permit implementation of image Quality Assurance Programs as well as Acceptance Procedures for monochrome display devices.

No Display Function Standard is available for the standardization of color display devices nor are there recommendations for image Quality Assurance Programs or Acceptance Procedures for color display devices.

This presentation demonstrates that consistent color presentation as well as consistent grayscale presentation for digital color displays can be achieved with the appropriate software and a simple and portable color detector. The software to achieve color fidelity works fast and, with the aid of the portable detector, can be applied remotely, saving precious resources in the management and operation of color displays.

The presentation also provides a look into the future when a handheld color camera will be available to permit in-field evaluation of pertinent image quality measures like modulation transfer function and signal-to-noise ratio of color display devices in the reading room.

TUESDAY, AUGUST 1

Imaging Continuing Education Course — Room 330 A

CE: Breast Imaging Physics and Technology - II

TU-A-330A-01

Digital Mammography Quality Control and Accreditation

P Butler*, American College of Radiology, Reston, VA

Digital Mammography Quality Control and Accreditation

Since 2003, the number of full-field digital mammography (FFDM) units in the United States has been increasing by about 4% per month. As of May 1, 2006, there were 1379 full-field digital mammography units at 977 MQSA-certified facilities in the United States. With the fall 2005 announcement that FFDM increased the effectiveness of detecting breast cancer in women with dense breasts (as well as premenopausal women and women under the age of 50), the rate of increase for digital units is expected to increase even further. FFDM systems are subject to the Food and Drug Administration's mammography regulations, as are analog systems). This presentation will discuss the steps medical physicists must take to ensure their facilities may expeditiously accredit their FFDM units. In addition, the presentation will cover preliminary QC recommendations made by the ACR's Subcommittee on Digital Mammography in preparation for their upcoming Digital Mammography FFDM Quality Control Manual.

Imaging Continuing Education Course — Room 330 D

CE: PET Physics and Technology – II

TU-A-330D-1

PET/CT Attenuation Correction and Image Fusion

J Patton*, Vanderbilt Univ Medical Ctr, Nashville, TN

In order for an annihilation event to be accurately detected in a PET scanner, it is necessary for both annihilation photons to pass through the patient without interaction and be detected by two detectors in the scanner. The probability of this occurrence is less than that for a single photon, resulting in significant attenuation effects in a PET scan. In the past, a positron source, such as Ge-68, was used as a transmission source to provide a transmission map to be used for attenuation correction. The recent integration of PET scanners with state-of-the-art multi-slice CT scanners has provided the capability for using the CT scan as a high-quality attenuation map to accomplish the task of attenuation correction. This has resulted in an improvement in the quality of the correction and thus an improvement in overall PET image quality. However this implementation has not been accomplished without additional problems being identified. Specifically beam hardening can cause errors in the attenuation correction and accurate corrections are difficult in regions where there is physiological motion such as the heart and lungs due to difficulties in accurately registered the CT and PET scans in these areas. Close attenuation must be paid to these effects.

Integration of the CT scanner with the PET scanner has provided a significant advance in clinical diagnosis and treatment planning because of the ability to accurately register and display high quality images of anatomy from CT and images of organ function from PET. This makes it possible not only to differentiate malignant from benign lesions but to also precisely localize malignant lesions and differentiate between abnormal uptake and normal physiological uptake of radiopharmaceuticals

Imaging Continuing Education Course — Valencia A

CE: Medical Imaging Informatics - II

TU-A-ValA-01

DICOM: What the Physicist Needs to Know

K Junck*, UAB Health System, Department of Radiology, Birmingham, AL

The DICOM (Digital Imaging and Communications in Medicine) standard has allowed for tremendous changes to occur in the workflow of a modern radiology department. Prior to DICOM, radiological images were generated, transmitted, and stored in proprietary formats by imaging vendors. DICOM provides a standard to define objects such as images and services that may be performed upon those objects. As with any disruptive technology, it has solved some problems and created a whole host of new issues. Some of these issues are being addressed within the DICOM standard while others have taken on a new life under the auspices of IHE (Integrating the Healthcare Enterprise). IHE is an initiative by healthcare professionals and industry to improve the way computer systems in healthcare share information.

This lecture is intended to provide an overview of the DICOM "language" and look at some current DICOM issues at our institution.

Educational Objectives:

1. Review the history of the DICOM standard and understand its origins and goals.
2. Understand the language of DICOM objects and services.
3. Understand the possible sources of DICOM issues.
4. Learn of available online resources for additional information.

Imaging Continuing Education Course — Valencia B

CE: Computed Tomography Physics and Technology - II

TU-A-ValB-01

Multi-Slice CT Artifacts and Quality Control

D Cody*, U.T.M.D Anderson Cancer Center, Houston, TX

Multi-slice CT Artifacts and Quality Control

This presentation will focus on examples and causes of artifacts produced by modern multi-slice CT scanners. Many of these artifacts were recognized because of a stringent quality control program implemented in our institution. The design of this quality control program will be described, along with its relative costs and benefits. Extending such a program among scanners produced by different vendors will be discussed.

Learning Objectives:

1. To recognize basic artifacts in patient and phantom images generated by modern multi-slice CT scanners.
2. To understand some basic requirements of a quality control program for multi-slice CT scanners.

Therapy Continuing Education Course — Room 224 A

CE: PET for Planning

TU-A-224A-01

Positron Emission Tomography for Oncologic Imaging and Treatment

J Bourland*, Wake Forest University, Winston Salem, NC

Purpose: Positron Emission Tomography (PET) images show physiological and biological information through the *in-vivo* distribution of radioactive, short-lived, positron-emitting species. PET imaging shows focal and distributed regions of cancer and its metastases. PET uses in oncology include diagnosis, staging, and disease monitoring, important for prognosis and treatment decisions. Quantitative uses of PET include assessment of the degree of malignancy and target definition for radiation treatment. Hybrid PET-CT devices are being used as radiation treatment simulators. **Method and Materials:** F-18-labled Fluoro-deoxyglucose (F-18 FDG) is the most commonly used PET imaging agent. FDG shows regions of active glucose metabolism, such as local cancer, metastases, non-cancer inflammation, and normal glucose use in brain. Non-FDG PET agents can be highly specific in tissue targeting (binding), such as F-18 Misonidazole and C-11-labeled amino acids, to image tumor biology like

hypoxia and cell proliferation, respectively. **Results:** PET imaging has coarse spatial resolution compared to CT and MR. PET's clinical use is valued because of its great sensitivity for cancer detection. Voxel intensity and image fidelity depend on equipment design, patient size, anatomic site, and imaging study parameters. PET-CT units enable CT-based attenuation corrections and inclusion of CT information in a registered PET-CT dataset. Interest is high for PET-CT simulators. The Standardized Uptake Value (SUV) is a normalized intensity measure for quantitative indication of disease, and can be used for target delineation, with certain constraints. **Conclusion:** This course reviews the basic physics of PET, uses of FDG and non-FDG PET for oncology imaging, and quantitative aspects for PET-based radiation target definition. Example images demonstrate the potential contributions and limitations of FDG and non-FDG PET oncology imaging. This review course is intended for both imaging and radiation oncology physicists.

Educational Objectives:
1. Review the basics physics of PET imaging
2. Describe FDG PET imaging and oncologic indications
3. Review the uses and limitations of PET images in radiation treatment
4. Describe the SUV and other threshold parameters for target delineation
5. Review non-FDG PET imaging of tumor biology

Conflict of Interest: Research sponsored in part by Varian Medical Systems and GE Healthcare.

Therapy Continuing Education Course — Room 224 C

CE: Dailiy Localization - II: EPID, MVCT

TU-A-224C-01

Daily Localization II: EPID, MVCBCT

J Pouliot*, UC San Francisco, San Francisco, CA

The Mega-Voltage Cone-Beam CT (MVCBCT) system provides a 3D image of the patient anatomy in the actual treatment position that can be tightly aligned to the planning CT, allowing daily verification and correction of the patient position moments before the dose delivery. Integrated onto a linear accelerator, the system consists of a new a-Si flat panel adapted for MV imaging and a workflow application allowing the automatic acquisition of projection images at low dose rate, CBCT image reconstruction, CT to CBCT image registration and couch position adjustment. Moreover, MVCBCT provides accurate electron density and allows studies of dosimetrical impact of setup error, anatomical changes or presence of implanted metallic objects.

This lecture will provide an overview of the physics characteristics of MV and MV CBCT imaging, acceptance testing and commissioning, acquisition and reconstruction, image registration, alignment precision and quality assurance procedures. An overview of the clinical applications will be provided. Finally, current challenges and future developments will be addressed.

Educational Objectives:
1. Understand the basics concepts of MV Cone-Beam CT imaging
2. Understand the workflow and issues related to clinical applications of MV CBCT, including acquisition, reconstruction, registration and patient alignment.
3. Understand the possibilities of 3D Imaging for patient alignment

This work was supported by Siemens Oncology Care Systems

Therapy Continuing Education Course — Room 230A

CE: Monte Carlo - II: Planning

TU-A-230A-01

Monte Carlo II: MC for Source and Machine Characterization

I. Chetty*[1], J. Siebers*[2], (1) University of Michigan, Ann Arbor, MI, (2) Virginia Commonwealth University, Richmond, VA

Monte Carlo algorithms have the ability to accurately model dose distributions for arbitrarily complex treatment delivery scenarios and changing patient geometries. These properties make Monte Carlo ideal for clinical planning, or for benchmarking clinical planning systems. Building on the discussion of the role of Monte Carlo in treatment head simulation (from the first course), this second Monte Carlo course will focus on patient planning applications. The goal of the course is to familiarize clinical medical physicists with the use of Monte Carlo in treatment planning, including advanced treatment techniques such as IMRT and motion compensated 4D treatment, and to discuss how Monte Carlo-based planning differs from planning with conventional algorithms. We will demonstrate the various approaches used in modeling beam modifying devices, such as the multi-leaf collimator (MLC), including methods to effectively model the dosimetric consequences of the detailed the MLC geometry. We will review methods used to reduce Monte Carlo-based clinical dose calculation time, such as variance reduction techniques, and discuss how factors specific to the MC method, such as statistical uncertainties, impact dose distributions and clinical decision making. We will illustrate how a properly benchmarked Monte Carlo algorithm can play a unique role in the modeling of complex delivery procedures, such as IMRT and how Monte Carlo fluence prediction can be combined with analytic dose algorithms to estimate patient dose. Finally, we will show how Monte Carlo can include organ motion in 4D dose calculations without an increase in computation time. In addition to illustrating the role of Monte Carlo in complex treatment planning, a focus of this course will also be to review some of the practical issues associated with the implementation, verification and clinical use of Monte Carlo-based dose calculation algorithms.

Educational Objectives:
1. To familiarize clinical physicists with some of the issues associated with implementation and experimental verification of Monte Carlo-based dose algorithms in the clinical setting.
2. To understand the factors specific to Monte Carlo-based dose algorithms, such variance reduction techniques and statistical uncertainties.
3. To become familiar with the various approaches used in Monte Carlo-based modeling of the MLC and the tradeoffs associated with these methods.
4. To recognize the potential clinical outcome benefits of Monte Carlo-based dose distributions.
5. To understand the use, benefits and limitations of the Monte Carlo method for IMRT optimization and QA.
6. To become familiar with the role of the Monte Carlo method in motion compensated (4D) treatment planning.

Imaging Continuing Education Course — Room 330 A

CE: Radiation Safety and Risk Management - II

TU-B-330A-01

Shielding Design Workshop: R/F Rooms

M Martin*[1], B Archer[2], (1) Therapy Physics, Inc., Bellflower, CA, (2) Baylor College of Medicine, Houston, TX

The application of the structural shielding design techniques and goals as outlined in NCRP Report 147: *Structural Shielding Design for Medical X-ray Imaging Facilities* (2004) will be the basis for this practical course. The wide variety of facilities installing
medical imaging equipment requires the medical physicist to consider an array of radiation protection concerns for the installation of radiographic/fluoroscopic equipment. To meet the challenge of maintaining construction costs to a minimum while providing adequate radiation shielding protection requires the physicist to utilize all available materials to reduce radiation exposure to surrounding personnel and the public. Estimating future workloads as well as considering current workloads for radiographic/fluoroscopic equipment as the medical imaging community transitions from a film/screen based world to a digital world can present challenges. Practical examples of these methods of structural shielding designs will be explored in this course.

Educational Objectives:
1. Understand the radiation exposure protection limits for surrounding areas of radiographic/fluoroscopic installations.
2. Understand the effectiveness of various shielding materials found in facilities to provide required structural shielding necessary to reduce anticipated radiation exposure levels to acceptable limits.
3. Understand the calculation of anticipated workloads for radiographic/fluoroscopic equipment and the effect of these workloads on structural shielding evaluations.

Imaging Continuing Education Course Room 330 D

CE: Radiography Physics and Technology - II

TU-B-330D-01

Design and Performance Characteristics of Flat-Panel Acquisition Technologies

J Yorkston*, Eastman Kodak Company, Rochester, NY

Flat-panel detectors are becoming more commonplace throughout the world for numerous applications ranging from mammography to megavoltage imaging and from static projection radiography to real-time fluoroscopy and cone beam CT. A detailed understanding of their advantages and limitations is essential to ensure their efficient integration into the clinical environment. This presentation will review their place in the current DR detector landscape and the unique features that provide them with their improved image quality performance when compared to other approaches. The differences and similarities between the various flat-panel designs will also be discussed with a view to highlighting their inherent image quality capabilities as well as some practical limitations to their performance. The process of gain/offset corrections will be reviewed and the issue of bad pixels, defective lines and image artifacts commented on. The implications of certain gain calibration procedures will be reviewed in terms of the possibility of image artifact creation, in particular in terms of other system components such as anti-scatter grids and AEC circuitry. The impact of non-linear behavior and pixel saturation will also be reviewed. In conclusion the development of advanced imaging applications such as dual energy, tomosynthesis and cone-beam CT will be reviewed.

Conflict of Interest: John Yorkston is an employee of Eastman Kodak Company which sells DR systems based on CsI(Tl) type Flat-Panel detectors.

Educational Objectives:
1. Review the range of DR and flat-panel detectors currently available and their design and performance differences.
2. Review the process of gain/offset calibration and its benefits and limitations.
3. Review the impact of pixel and line defects, correlated line noise, pixel saturation and other characteristics behaviors of flat-panel detectors.
4. Review the prospect of advanced applications utilizing flat-panel technology.

Imaging Continuing Education Course Valencia A

CE: Fluoroscopy Physics and Technology - II

TU-B-ValA-01

Digital Fluoroscopic Imaging: Acquisition, Processing and Display

B Belanger*, GE Healthcare, Wauwatosa, WI

The modern digital fluoroscopic imaging system has evolved to levels of complexity and automation that, when properly applied, can provide enhanced clinical performance and flexibility over a wide range of clinical applications in a user-friendly manner. However, achieving maximum performance from such complex systems may be best achieved through cooperative efforts between manufacturers and clinical users, in which the well-informed clinical team can utilize the degrees of freedom available in these systems to achieve the best clinical results for each medical application of interest. The medical physicist plays an important role in this process as the person who understands the relationships between physical imaging parameters, dose, and clinical imaging performance. Therefore, an understanding of system architectures, design philosophies, image processing capabilities, and degrees of freedom in procedure programming allow the medical physicist to play a more effective role. To this end, an overview of modern digital fluoroscopic imaging system will be presented, with particular attention given to the range of fluoroscopic and record imaging modes provided, automatic exposure control systems, common image processing algorithms, and procedure protocol selections. Recommendations for minimizing pitfalls in equipment testing will also be presented, along with some of the unique considerations for flat panel detectors versus image intensifier-based imaging systems.

Research sponsored by GE Healthcare.

Educational Objectives:
1. Understand the architecture of modern fluoroscopic systems, including major image and data communication pathways, control systems, and image processing from acquisition to display.
2. Gain familiarity with the flexibility in control and processing afforded by new technologies and architectures, and how manufacturers use these.
3. Be aware of the various fluoroscopic imaging modes and the related image quality and dose considerations, including dose monitoring and reporting.
4. Understand common image processing techniques, such as edge enhancement, multiband filtering, and temporal filtering, and their impact on image quality.
5. Recognize the unique aspects of Digital Flat Panel Detectors and the related implications for fluoroscopic system behavior and performance.
6. Be able to identify the types of automation implemented in systems, and know how to avoid related pitfalls in testing.
7. Recognize the various procedure protocol programming capabilities available, and how they may be customized to meet clinical objectives.

Imaging Continuing Education Course Valencia B

CE: MRI Physics and Technology - II

TU-B-ValB-01

The Principles of Quantitative MRI

GD Clarke*, UT Health Sciences Center, San Antonio, TX

The applications of magnetic resonance imaging (MRI) in biomedicine are undergoing rapid evolution. Typically used to produce images that are viewed and subjectively rated by a radiologist, MRI is now being utilized as a scientific apparatus capable of making noninvasive measurements in living tissues. With care, a significant number of physical and biological measurements can be performed and related to individual pixels and groups of pixels in the MR image. This presentation will address the challenges in obtaining quantitative data from MRI.

The presentation will review the principles of good practice in quantification, including quality assurance, MR data collection, and analysis. Limits on precision and accuracy are discussed and solutions proposed. Three major measurement topics are considered. First, geometrical quantities, such size, position and grouping of structures are discussed. Then, MRI signal-derived quantities such as proton density and relaxation times are considered. Third, physiological quantities such as diffusion coefficients and measures of blood flow and perfusion are explored. The principles underlying the measurement of each quantity are given along with their biological and medical significance and practical approaches for their measurement. Shortcomings of the measurement processes and a summary of potential clinical applications are also discussed. Pathological observations are also compared with MRI-derived quantities where appropriate.

This presentation is intended as an introduction to the field of measurement in MRI for anyone who desires to use the scope of modern measurement techniques to quantitatively determine the consequences of disease, its development or its reaction to therapy from MR images. It will be of interest to medical physicists who are considering undertaking quantitative work with MRI, as well as those already in the field.

At the end of this session the attentive participant shall:
1. Appreciate the clinically important quantities that can be measured with MRI
2. Be familiar with the methods and techniques used for quantitative MRI
3. Have a basic understanding of the limits on precision and sources of error in quantitative MRI

Therapy Continuing Education Room 224 A
Course
CE: Shielding II: New NCRP Report: Linac

TU-B-224A-01
Shielding II:Linac Radiation Monitoring and Surveys: Instruments and Methods
N. E. Ipe*, Consultant:Shielding Design, Dosimetry & Radiation Protection, San Carlos, CA

Regulatory agencies typically require shielding integrity radiation surveys during commissioning of radiation therapy linear accelerators (linacs). While concrete barriers that provide adequate shielding for photons also provide adequate shielding for neutrons, facilities operating at energies above 10 MV shall be checked for neutrons at the door, maze entrance, and any other openings through the shielding. Laminated barriers shall be monitored for neutrons beyond the shielding.

For the primary barrier measurements, the maximum field size is utilized without a phantom in the beam. Gantry angles of 0, 90, 180, 270 degrees as well oblique angles depending upon the shielding configuration are commonly used. Secondary barriers are surveyed with the maximum field size and a phantom in place.

Photon surveys outside the barriers are performed typically with a calibrated ionization chamber which has both rate and integrate modes, at 30 cm from the barrier. Head leakage in the linac room can be established with the use of film wrapped around the linac head and integrating dosimeters.

In this lecture neutron monitoring will be emphasized. Neutron measurements inside the treatment room are fraught with difficulties because of photon interference from the primary and leakage photon beam and the fact that neutron detection is spread over many decades of energy. Thus no single neutron detector can accurately measure neutron fluence or dose equivalent over the entire energy ranges. Additionally neutron detectors can have photon-induced reactions when used in the primary photon beam. Further because therapy linacs are operated in a pulsed mode, the intense photon pulse overwhelms any active detector that detects particles electronically. Thus active detectors such as such as neutron rem-meters, fluence meters and spectrometers neutron cannot be used inside the treatment rooms except at or near the maze entrance. They can be used outside the shielded treatment room.

Passive monitors with high neutron sensitivity such as moderated activation foils (gold and indium) and threshold activation detectors (phosphorous) can be typically used inside the treatment room and inside the primary beam. Moderated activation foils can also be used inside the treatment room and outside the primary beam. Solid state neutron detectors (SSNTDs) such as CR-39 ® and bubble detectors can be used inside the treatment room, but outside the primary beam. Bubble detectors can also be used for radiation surveys outside the shielded treatment room.

Educational Objectives:
1. Understand how to perform shielding integrity radiation surveys
2. Understand the various neutron monitoring methods and instruments
3. Understand under which conditions these monitors can be used

Therapy Continuing Education Room 224 C
Course
CE: 4D Scanning

TU-B-224C-01
4D Scanning
S Jiang*, Massachusetts General Hospital and Harvard Medical School, Boston, MA

The purpose of CT simulation in radiotherapy is to acquire patient geometrical information and to build a patient geometrical model for treatment planning. Errors in patient model caused by motion artifacts will influence all treatment fractions and therefore should be handled carefully. Due to the tumor respiratory motion, the captured tumor position and shape can be heavily distorted. The distortions along the axis of motion could result in either a lengthening or shortening of the target. The center of the imaged target can be displaced by as much as the amplitude of the motion.

A newly developed technique that can reduce motion artifacts and provide patient geometry throughout the whole breathing cycle is called respiration-correlated or 4D CT scan. The basic idea for 4D CT scan is that, at every position of interest along patient's long axis, images are over-sampled and each image is tagged with breathing phase information. After the scan is done, images are sorted based on the corresponding breathing phase signals. Thus, many 3D CT sets are obtained, each corresponding to a particular breathing phase, and together constitutes a 4D CT set that covers that the whole breathing cycle. 4D CT scan has been developed at various institutions with slightly different flavors. In this lecture, we will provide an overview of various implementations of 4D CT scan.

4D CT scan can be used to account for respiratory motion to generate images with less distortion than 3D CT scan. 4D images also contain respiratory motion information of tumor and organs that is not available in a 3D CT image. This technology can be used for respiratory-gated treatment to identify the patient-specific phase of minimum tumor motion, determine residual tumor motion within the gate interval, and compare treatment plans at different phases. It can also be used for non-gated treatment planning to define ITV by combining gross tumor volume at all breathing phases or using a method called maximum intensity projection. Of course 4D CT will also play a vital role in the futuristic 4D radiotherapy where the tumor is tracked dynamically during the treatment using multi-leaf collimator.

Existing problems for 4D CT scan include the increased imaging dose, CT tube heating, and data management. More importantly, one has to keep in mind that 4D CT scan is not really 4D. Temporal information is mapped into one breathing cycle. Irregular respiration will cause artifacts in 4D CT images. Patient coaching can improve the regularity of breathing pattern and thus reduce the residual artifacts. However this issue still deserves further studies.

Educational Objectives:
1. Understand the origin and magnitude of motion artifacts in free breathing helical CT scan
2. Understand how 4D CT scan works
3. Understand how 4D CT can be used in radiotherapy
4. Understand the remaining artifacts in 4D CT scan and possible future improvements

Therapy Continuing Education Room 230A
Course
CE: Informatics Systems Overview

TU-B-230A-01
Informatics Systems Overview
R Dahl*, M Herman, Mayo Clinic, Rochester, MN

Due to the increasing complexity of radiation therapy, government regulations, and legal liability, computerized radiation oncology information systems are becoming a necessity. Selection of an information system involves understanding of both computer software and hardware

issues. Topics such as network infrastructure, software interfaces, and hardware interfaces, which are not part of the normal physics training, must be understood by the medical physicist. As the person with the most technical training in the radiation oncology department they will be called upon to do one or more of the following; specify a system, setup and installation, troubleshoot the system when things go wrong. This course will identify both hardware and software issues to consider when either first implementing a computerized information system or changing to an electronic treatment record. An overview/summary of the commercially available Record & Verify systems will also be presented.

Educational Objectives:
1. Understand basic network infrastructure for both local area networks (LAN) and wide area networks (WAN).
2. Understand interfaces to both hospital information systems and various radiation oncology devices.
3. Understand differences in network requirements for both single department and multi-department institutions.
4. Understand what is required when migrating from a paper treatment record to an electronic treatment record.
5. Be able to generate specifications for a radiation oncology information system.
6. Understand the personnel requirements for implementing and maintaining a radiation oncology information system.

Conflict of Interest Statement
Michael Herman - Research sponsored by Varian Medical Systems Corporation.

Imaging Scientific Session Room 330 A

Joint Imaging-History Scientific Session: MRI and Multi-Modality Imaging

TU-C-330A-01

The History (and Future) of MRI Physics

T Roberts*, University of Pennsylvania School of Medicine, Philadelphia, PA

The history of MRI is now a little over 30 years old. It's impact on the scientific, and in particular medical, community has been immense, and shows no sign of slowing. From the first demonstration in 1973 of the spatial encoding of proton density information in the nuclear magnetic resonance signal, via the application of pulsed magnetic field gradients, a succession of technological developments now makes MRI the modality of choice for a wide range of cross sectional biomedical imaging applications. This talk will offer some insights into the origins of MRI, the rapid development of spin echo and gradient recalled echo, 2D and 3D, imaging and the birth of faster and faster imaging involving multiple echoes (RARE and echo planar imaging). Additionally, interpretation of MRI-accessible contrasts emerged, offering specific insights into physiology via NMR relaxation time constants and such MRI "flavors" as diffusion weighted imaging. In parallel, MRI-specific contrast media ("magnetic dyes") were introduced in the 1980's offering both "enhancement" of MRI signal as well as the opportunity to study dynamic processes (such as bolus tracer passage, with concomitant estimation of perfusion and, later, microvascular permeability). The 1990's saw the continued clinical adoption of MRI as well as the commitment to physiologically-specific imaging and the introduction of blood oxygenation level dependent (BOLD) contrast and the birth of "functional magnetic resonance imaging, fMRI", for the spatial mapping of brain functional organization. More recently yet further acceleration in image acquisition speed has been offered by the introduction of multiple (parallel) receiver coil elements and the adoption of the principles of sensitivity encoding. Presently, acceleration factors of x2 are routine, x4 are commonplace and x9 or more are in development. The future offers the possibility of massively parallel acquisitions with effectively single-shot temporal resolution of the order of milliseconds. While the contrast resolution of MRI is transitioning from anatomy through physiology towards biochemical processes, the speed of MRI is accelerating from static to real-time, hurdling successive physical and physiological boundaries (such, as involuntary motion, breath-hold, cardiac cycle and ultimately towards the speed of neuronal processes). The overall vision of this talk is to convey the ongoing development of MRI towards both increasing spatial and temporal resolution as well as towards increasingly specific biological interpretation.

Educational Objectives:
1. To understand the origins and background of today's MRI
2. To understand the rapid development of MRI acquisition speed
3. To understand the use of tailored MRI to derive physiologically specific image contrast
4. To anticipate the continued acceleration of both imaging speed and biological application of MRI

TU-C-330A-02

Patterns of Brain Tumor Recurrence Predicted From DTI Tractography

A Krishnan*, I Asher, D Davis, D Fuller, P Okunieff, W O"Dell, University of Rochester, Rochester, NY

Purpose: Approximately 170,000 new cases of brain metastases and 17,000 cases of primary brain cancer are diagnosed in the United States each year. Stereotactic Radiotherapy (SRT) is fast becoming the method of choice for treatment of non-superficial brain lesions. SRT treatment plans of malignant and metastatic brain tumors typically incorporate a 2 cm margin to account for microscopic tumor spread, however, distant and/or recurrent tumors sometimes occur. Our hypothesis is that paths of elevated water diffusion may provide a preferred route for transport or migration of cancer cells through an unknown mechanism. If our hypothesis is correct then future SRT treatment would be modified to provide elongated treatment margins along the paths of elevated water diffusion leading from the primary tumor site; thereby reducing the incidence of recurrence and improving clinical outcomes. **Method and Materials:** MR diffusion tensor imaging datasets were acquired in patient subjects treated with SRT of malignant and/or metastatic brain tumors. DTI was performed using an EPI sequence on a 1.5T clinical GE scanner with 20 serial axial images of voxel dimensions 0.976×0.976×6 mm; TR 10s; TE 89.4 ms; 25 diffusion gradient directions plus 3 reference (b=0) scans. Following SRT, patients were given repeated MRI follow-ups at regular intervals to identify early tumor recurrence. When recurrent tumors were detected, DTIstudio and FSL software was used to compute paths of preferred water diffusion through the primary tumor site and the site of recurrence. **Results:** There exists an apparent correlation between patterns of recurrence in the brain and paths of elevated diffusion leading from the primary brain tumor. **Conclusions:** Our preliminary results on a small number of patient datasets suggest that this hypothesis is correct and further investigation is warranted. Future work will employ a more sophisticated fiber analysis on additional patient images and verification with animal models.

TU-C-330A-03

Sulci Density Map to Aid in the Use of Apparent Diffusion Coefficient for Therapy Evaluation

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Sulci Density Map to Aid in Use of
Apparent Diffusion Coefficient for Therapy Evaluation

Purpose: To quantify the density and spatial variation of sulci in the human brain so as to more accurately calculate Apparent Diffusion Coefficients (ADCs) for use in radiotherapy evaluation. **Methods and Materials:** ADCs are calculated for Volumes Of Interest (VOI) using Diffusion Weighted Magnetic Resonance Imaging (DWMRI).

In the brain, the sulci are the narrow fissures separating convolutions and are filled with CerbroSpinal Fluid (CSF). Since CSF is free fluid, a VOI that contains a high density of sulci should, in principal, have a higher ADC

Using ImageJ (http://rsb.info.nih.gov/ij/), we have analyzed sagittal T1 weighted MR images of a number of patients. The images sets were acquired on one of two different GE MRI machines: 1.5T and 3.0T field strength. We have plotted the normalized pixel standard deviation, as a function of distance from a medial point. We have concentrated on the cerebral hemispheres, superior to the corpus callosum so as to focus on sulci and avoid voxel dissimilarities due to variations in other brain anatomy. **Results:** Relative to the 25% most medial slices, we see a decrease in the normalized standard deviation of pixel intensity of 13.7% ± 5.6% (SD) of the next 25% of the slices. The most lateral 50% of the slices

(25% left and right) had about the same normalized standard deviation as the most medial (increase of 1.0% ± 7.1% (SD)). These results are consistent with the fact that near the periphery of each brain hemisphere, there are more sulci. **Conclusion:** Sulci density, as measured by normalized standard deviation of pixel intensity, has a substantial variation across the hemispheres of the brain. This fact should be considered when assessing variations in ADCs used for radiotherapy evaluation.

TU-C-330A-04

Preliminary Study of Glu and Gln Metabolites in Brain Tumors at a 4T System

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Purpose: *in vitro* 1H MRS studies have suggested that Gln/Glu ratio is useful in detecting an early stage of malignant transformation. Due in part to the technical difficulty, *in vivo* detection of well-separated Gln and Glu of human tumors has not been reported. A recent study proposed that a standard STEAM sequence with optimized TE/TM (80/50 ms) can be used to simultaneously detect Gln and Glu peaks around 2.4 ppm with virtually no spectral overlap at 4T. In this study, we report preliminary results of the application of this technique for brain tumors. **Method and Materials:** 1H MRS of eight patients with brain tumors were acquired with a quadrature head coil in a 4T system. Four patients had biopsies within two weeks of their respective MRS study, and the remainder had biopsies prior to their scans. A standard STEAM sequence was used with TE=80ms, TM=50 ms, TR = 2 –3 seconds, spatial resolution = 4 - 12 cm^3, and acquisition time =15-30 minutes. All data sets were processed using LCModel. **Results:** In addition to providing "typical" characteristics of NAA, Cho, and Cr for brain tumors, one of the striking observations is consistent and remarkable increase in Gln concentration (water as reference) and Gln/Cr ratio for all cases studied; while decrease in Glu concentration (water as reference) but wide variability in Glu/Cr ratio (0-3 times of corresponding contralateral control). The results also demonstrate occurrences of opposite changes between Gln and Glu content for brain tumors, illustrating the importance of simultaneously detecting Gln and Glu for the study of tumor metabolism. The consistent and remarkable increases in Gln content suggest direct Gln involvement in tumor metabolism, in agreement with previous biochemical analysis. **Conclusion:** In vivo Glu, Gln can provide useful information to help diagnosis of brain tumors.

TU-C-330A-05

Optimization of Outer Volume Suppression for Improved Prostate MR Spectroscopic Imaging

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Purpose: To adapt a new MR Spectroscopy (MRS) technique employing non-cuboidal voxels, called conformal voxel MRS (CV-MRS), for use in prostate spectroscopic imaging in order to reduce contamination of spectra by lipid signal surrounding the prostate.

Method and Materials: CV-MRS uses twenty or more spatial saturation (SS) pulses, placed around the prostate, to reduce the lipid signal affecting the spectra within the prostate. A water/oil phantom was designed to simulate the prostate and surrounding lipid signal. Use of the new CV-MRS technique reduced the lipid signal contamination by 84% as compared to standard cuboidal voxel MRS. To further reduce the lipid contamination, the routinely used 90 degree flip angle used for each SS pulse was modified to take into account the regrowth of lipid signal with its short T_1 relaxation time. **Results:** Contrary to our expectations, resulting spectra from the optimized approach actually showed an increase in lipid contamination by 10%. We tracked the problem down to overlapping SS pulses. Using a simulated 3D model, we found that 68% of the volume we were trying to saturate experienced multiple overlapping SS pulses, with some regions being saturated 7 or more times. Regions of the volume experiencing an even number of SS pulses were found to increase the lipid contamination signal by 88% to 200%. Conversely, regions experiencing an odd number of SS pulses had a reduction in lipid contamination of 55%. **Conclusion:** Changing the ordering of the SS pulses, such that the overlapping pulses occur later in the train of 20 SS pulses reduced the problem of lipid signal from those overlapping volumes. In summary, we have developed an improved outer volume saturation technique which reduces lipid contamination problems in prostate MR spectroscopic imaging.

TU-C-330A-06

Evaluation of Internal Lung Motion Based On Extended Time Ultra-Fast MRI Scan

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Purpose: In order to develop radiation treatment planning based on a displacement probability function for lung tumors we developed a dynamic MRI protocol to image the internal human respiratory lung motion during a several minute period that simulates the duration of a radiation treatment, evaluated the long time displacement probability distribution function (PDF) of pulmonary vessels as surrogate tumors, and assessed its reproducibility with repeat imaging. Methods and Materials: TrueFISP (fast imaging with steady-state precession) sequence was adapted to acquire real time MR images of human lungs during 5 minute scans in both sagittal and coronal planes. A total of 26 pulmonary vessels from different regions (upper, middle and lower) in 3 healthy subjects were examined. Motion profile and displacement PDF of each tracked pulmonary vessel were evaluated. Experiments were repeated after 2-3 weeks to test the reproducibility. **Results:** Motion profiles and displacement PDF of the same subject showed similarity, but great variation between different subjects. Displacement PDFs varied tremendously but tended to stabilize during the 5-minute scan, and were reproduced reasonably well to various degrees in the repeated experiments after a subject specific stabilizing time (270s, 120s, 200s for Subject 1, 2, 3 respectively). **Conclusions:** Experiments for the first time using ultra-fast real time MRI in extended time scans produce stable and reproducible displacement PDF of internal pulmonary structures, weakly depending upon different individual breathing patterns. This methodology is being investigated in a clinical trial at our institution to determine in a larger scale whether the reproducibility of motion is statistically significant and whether patients with lung tumor exhibit similar predictable breathing characteristics.

TU-C-330A-07

Magnetic Resonance Electrical Impedance Mammography: A Feasibility Study

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Purpose: To demonstrate the feasibility of a new imaging technique consisting in simultaneous Magnetic Resonance Mammography and Electrical Impedance Scanning of the breast which does not require theoretically fat suppression and injection of paramagnetic contrast agents. **Method and Materials:** A theoretical formulation of the expected signal was developed and verified by the computer simulation demonstrating the distortion of the magnetic field caused by the injected currents. Two conducting breast phantoms were designed using breast tissue and tumor equivalent materials: (a) a soap phantom with a soap and salt solution as a cancer surrogate and (b) an agar phantom with a piece of fat-free hotdog as a cancer surrogate. The stabilization paddles in a Symphony Breast Biopsy Array were modified to include Faraday shield electrodes fed by a variable frequency power source. The phantoms were placed between the modified paddles and imaged with a Siemens Magnetom Symphony Maestro Class 1.5 Tesla system with the current densities reaching 4.5 A/m^2 and frequencies ranging from 200 Hz to 1000 Hz. Gradient re-phased, spin echo, and echo-planar sequences were tested to maximize the expected output signal. The images were subjected to statistical analysis to determine a set of parameters which produce detectable signal with minimal injected currents. **Results:** The expected signal was observed in agreement with the simulation. The agar phantom proved to be more stable and showed consistency in the imaging results. A large number of variables, including imaging sequence parameters, experimental setup parameters, and phantom quality, requires a more thorough analysis of the

proposed technique. **Conclusions:** We have demonstrated the feasibility of simultaneous magnetic resonance and electrical impedance imaging that has the potential to revolutionize current Magnetic Resonance Mammography. A significant effort should be put into optimization of imaging parameters at minimum current without compromising patient safety or signal quality.

TU-C-330A-08

X-Ray Tube Induction Motor Performance in a 1.5 T MRI Fringe Field

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Purpose: To assess the performance of the induction motor of a rotating-anode x-ray tube in the magnetic fringe field of a clinical MRI scanner. The x-ray tube must be placed in the fringe field near the entrance of an MRI scanner so that a hybrid x-ray/MRI system for use in percutaneous aortic valve replacement in aortic stenosis patients can be constructed. **Method and Materials:** A standard rotating-anode x-ray tube insert was placed into the fringe field of a 1.5 T unshielded research MRI scanner. The induction motor in the x-ray tube was aligned so that the magnetic field lines were in the plane of its stator core. The induction motor of the x-ray tube was placed in magnetic fields ranging from 0 to 500 G. The magnetic fields were measured with a Model 4048 Gauss meter. The rotation speed of the anode was measured using a strobe light. The power consumed by the motor during operation in the fringe field was measured separately using a PLM-1 power meter. The fringe fields of an actively shielded clinical 1.5 T scanner were measured with the Gauss meter and compared to the fields applied to the motor. **Results:** The anode rotation speed dropped from 3437 +/- 6.8 rpm to 2744 +/- 5.3 rpm when the magnetic fringe field was increased from 0 to 400 G. The average power consumed by the motor increased from 70.5 +/- 0.4 W to 78.2 +/- 0.1 W when the fringe field was increased from 0 to 500 G. **Conclusion:** This work indicates the feasibility of safely operating an x-ray tube induction motor in the fringe field of an MRI scanner. Power consumption did not significantly increase and anode rotation speed did not fall below 3000 rpm until a fringe field exceeding 300 G was applied.

TU-C-330A-09

Performance of CT and MR-Based Assays for In Vivo Agent Concentration Quantitation

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Purpose: To investigate the feasibility of performing longitudinal image-based measurements using CT and MR to estimate contrast agent concentrations in organs and tissues *in vivo*. **Method and Materials:** A CT and MR contrast agent (200 mg/kg of iodine and 16 mg/kg of gadolinium encapsulated in liposomes) was administered intravenously to a 2 kg New Zealand White rabbit. At 5 minutes, 24, 48, 72, 96, 120 and 168 hours following contrast injection, the rabbit was imaged in CT (120kV, 200mA) and in MR (3D FSPGR, TR/TE= 9.8/4.3). 1mL of blood was collected from the same rabbit at each of the above times. The rabbit liver and spleen were harvested at the study end point (168 hours). The blood and tissues samples were then analyzed using high performance liquid chromatography (HPLC) to measure iodine content and inductively coupled plasma atomic emission spectrometry (ICP-AES) to measure gadolinium content. **Results:** The differential blood CT attenuation vs. plasma iodine concentration correlation was well approximated with a linear fit (R^2=0.9), while the differential blood MR signal intensity vs. plasma gadolinium concentration correlation was found to be nonlinear. These correlations were used to estimate the iodine and gadolinium content in the liver and the spleen. Using the CT correlation, the liver and the spleen iodine content were estimated to be 70% and 60% of the extracted amounts, respectively. The MR-based method did not yield satisfactory gadolinium content estimates. **Conclusion:** This study attempted to correlate CT attenuation and MR signal increases to local iodine and gadolinium concentrations, respectively. In CT, the linear correlation obtained with blood data allowed for estimation of iodine content in the liver and spleen to 60-70% accuracy. In MR, although the presence of the contrast agent could be detected visually over a 7-day period, additional effort is required to achieve reliable agent concentration estimations.

Imaging Symposium — Room 330 D

Advances in Breast Imaging

TU-C-330D-01

Advances in Breast Imaging

C Shaw*, UT M.D. Anderson Cancer Center, Houston, TX

Despite development and advances of new modalities, x-ray mammography remains the main screening tool for early detection of breast cancers. It also continues to play an important role in the diagnosis and management of breast cancers. X-ray mammography has relied on the use of high resolution screen/film combinations. Such techniques, although improved over the years, have the drawbacks of all the inconveniences and inflexibility associated with the use of film for image acquisition, storage and display. Motivated by search for better image quality and a general move towards filmless radiology, various digital mammography techniques have been developed, investigated and commercialized. These techniques can be largely divided into four types: amorphous silicon and selenium flat panel detector, amorphous silicon and cesium iodide flat panel detector, CCD and cesium iodide based slot scanning system, and storage phosphor imaging technique with dual-side image read out. Each of these systems has its unique advantages and disadvantages and achieves various degrees of clinical implementation. Typical of all digital mammography techniques is the potential compatibility with digital image archival, retrieval and distribution systems. Furthermore, the acquisition of breast images in digital format has begun to facilitate the development and investigation of many advanced imaging techniques. Among them, dual-energy mammography techniques have been developed to quantify breast tissue composition or to separate calcifications from the overlying tissue structures. Stereo-mammography has been developed to use two projection views to provide a 3-D perspective of the breast tissue structures, thus reducing the problem of overlapping structures. Tomosynthesis imaging pushes the idea of 3-D imaging further by acquiring 10-25 projection views and use them to synthesize images to depict the breast structures as a number of thick layers. More recently, cone beam breast CT has been developed and investigated to scan the breast in a dedicated manner and provide true 3-D images of the breast. Along a different direction, the development and investigation of various contrast mammography techniques have allowed x-ray imaging to be used to image and study breast vasculatures as possible indication of breast cancer.

In this presentation, we will try to achieve the following educational objectives:

1. Review the development and investigation of major digital mammography techniques
2. Review the development and investigation of various advanced breast x-ray imaging techniques

Research sponsored by the National Cancer Institute and the National Institute of Biomedical Imaging and Bioengineering.

TU-C-330D-02

Digital Breast Tomosynthesis

A Maidment*, University of Pennsylvania, Philadelphia, PA

Both film-screen and digital mammography are subject to a number of fundamental limitations related to the projection process, whereby 2D images are produced of the 3D breast anatomy. Mammography can produce artifactual densities from the superposition of normal tissues that are separated in space; although only visible in a single view, these often appear sufficiently suspicious to necessitate a biopsy, leading to a loss in specificity. Furthermore, true lesions in mammograms can be masked by superimposed normal tissue and thereby rendered undetectable; this reduces the sensitivity of mammography.

Numerous tomographic methods have been proposed to overcome these limitations, including digital breast tomosynthesis (DBT). DBT is a tomographic imaging technique in which a set of tomographic images can be reconstructed from a limited number of x-ray projection images. DBT has the potential to mitigate against both the superposition of non-adjacent tissue (false positive densities) and the masking of real lesions (false negatives) observed in projection mammography, while also providing a simple means of localizing lesions in 3D. A preliminary retrospective

study of breast tomosynthesis by Rafferty et al. has demonstrated a 16% increase in sensitivity and 85% decrease in false positives as compared to digital mammography. Our own experience at the University of Pennsylvania with 51 patients has provided supported anecdotal evidence.

DBT also offers the potential for functional imaging. Breast tumor growth and metastasis are accompanied by the development of new blood vessels. We have used a modified GE 2000D under IRB approval, to gain initial experience in contrast-enhanced DBT (CE-DBT). To date we have acquired 13 CE-DBT clinical cases. Suspicious enhancing lesions were demonstrated with CE-DBT in 10 of 11 cases of pathology-proven breast cancer. The cases illustrated that CE-DBT could provide information in concordance with multimodality imaging evaluation. The pre-contrast tomosynthesis images demonstrated lesion morphology and border characteristics in greater detail than the digital mammography images, and the CE-DBT data sets demonstrated vascular characteristics of the breast lesions of interest that were consistent with the vascular information provided by MR. In addition, quantitative evaluation of contrast uptake is anticipated to be more easily standardized with CE-DBT due to the linear relationship between attenuation and contrast concentration compared to MRI.

In this presentation, the following education objectives will be addressed:
1. Review the development and design of digital breast tomosynthesis systems.
2. Evaluate the results of the existing DBT clinical trials.
3. Examine advanced applications of DBT including contrast-enhanced DBT and CAD.
4. Compare DBT to other x-ray tomographic imaging modalities.

TU-C-330D-03

Computed Tomography of the Breast: Design, Fabrication, Characterization, and Initial Clinical Testing

J Boone*, T Nelson, A Kwan, K Yang, University of California Davis

Purpose: Although there is overwhelming evidence that mammographic screening has led to a reduction in breast cancer mortality, most breast imaging experts agree that screening technology could be improved. We have developed a dedicated breast CT scanner which may be appropriate for breast cancer screening in some groups of women. **Methods and Materials:** A breast CT scanner was designed and fabricated in our laboratory using off-the-shelf components (an x-ray system, flat panel detector, and motor) and custom-manufactured parts. Image quality was assessed subjectively in terms of artifacts, and by conventional metrics (MTF for spatial resolution, RMS noise, etc.). Radiation dose levels were adjusted to be comparable to two-view mammography, using a series of physical measurements and Monte Carlo computations. Evaluation in patients has begun with both Phase I and Phase II clinical trials. **Results:** The spatial resolution of the bCT system exceeds that of commercial scanners, with a 10 percent MTF corresponding to XX inverse mm (center of field, 80 kVp, 500 views). Noise metrics demonstrates that the scanner performs in a quantum limited manner. Ten healthy volunteers have been scanned, and as of this writing 35 women with BIRADS 4 or 5 diagnoses have been scanned. Subjective evaluation of image quality clearly indicates detail not seen mammographically. The volume dataset (300 512 x 512 pixel images) can be displayed in coronal, axial, saggital or any arbitrary view angle. **Conclusions:** The clinical evaluation of the bCT system is underway, and early subjective results have generated interesting images with excellent anatomical depiction. The use of contrast agents has added a functional component to breast CT imaging. Further patient accrual with subsequent quantitative (ROC) analysis is needed.

Learning Objectives:
1. Status of breast CT implementation at UC Davis

Joint Imaging/Therapy Valenica A
Scientific Session
The John S. Laughlin Science Council Research Symposium: Multi-Modality Image Fusion and Deformable Registration

TU-C-ValA-01

Image Fusion and Deformation Using a Genetic Algorithm

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Purpose: To develop an image fusion application utilizing genetic algorithms, segment the fused images using treatment-planning contours, perform a slice-by-slice sub-fusion of the segmented images in order to measure deformation, and then utilize the measured deformation for adaptive therapy on a helical tomotherapy treatment delivery. Methods and Materials: A reference CT image of a density and spatial resolution phantom was obtained using a MVCT imaging. A secondary MVCT fusion image was obtained with the phantom offset by a known amount with plugs removed or rotated. An image fusion algorithm was created using genetic programming to perform image registration of the MVCT images. Contours of the plugs were used to extract sub-images that were separately registered and deformed using the genetic algorithm. Adaptive therapy was achieved thorough a treatment delivery sinogram deformation algorithm. The sinogram deformation algorithm was tested using a geometric test case that consisted of a dose triangle with a 5.2-cm base located inside a dose circle with of 3.14-cm radius. The test dose pattern was moved by known amounts by deforming the treatment delivery sinogram. **Results:** The initial genetic fusion of the reference and secondary MVCT images was achieved in approximately 15 generations. The time required to perform the genetic fusion was typically 10 to 15 seconds. The images were fused to within 0.7-mm of the correct position. At the end of the initial fusion, the genetic algorithm correctly identified one of the plugs as missing in the secondary MVCT dataset. The genetic algorithm correctly segmented the second resolution plug in a sub-image and deformed it to within 1-degree and 0.7-mm of the correct position. The delivery deformation tests moved the dose to within 5-mm of the desired position. **Conclusions:** A genetic algorithm has been developed for performing image fusion and simple deformation of defined regions of interest.

TU-C-ValA-02

A Simple Iterative Method to Invert a Deformation Field

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Purpose: Inversion of a deformation field is applied frequently to map dose and regions of interest to a reference frame. A prevailing naïve approach that takes the opposite displacement of the forward deformation as the displacement of the inverse is mathematically wrong and can cause large errors for large or accumulative deformation. Inversion by "scattered data interpolation" has $O(N^2)$ complexity and is difficult to implement. We propose a simple iterative approach with $O(N)$ complexity. **Method:** Instead of calculating the inverse, we calculate the displacement of the inverse. The displacement of the inverse is iteratively refined through the displacement of the forward map. We prove that such iterative scheme converges exponentially to the true solution when the deformation field is subject to a condition of the Lipschitz type. The Lipschitz type condition essentially states that the difference of the deformation of two points can not be too far. This is a mild restriction on the deformation field and is usually a valid assumption for any deformable registration method with regularization.
Results: We tested the proposed method on both simulated 2D data and real 4D CT data of lung patient. The simulations showed that the proposed method has exponential convergences to the true inverse. For real 4D CT data, the forward deformation field constructed by deformable registration mapped the test phase to the reference phase and the inverse of that deformation field accurately map the reference phase to the test phase. **Conclusions:** A simple, accurate and fast method for inverting a

deformation field is presented. Both the mathematical proof and the simulations showed its exponential convergence. Simulations and real data tests demonstrated its efficacy in medical image analysis and radiotherapy applications. Typically less than 10 iterations are needed to get an inverse deformation field with clinically relavent accuracy.

TU-C-ValA-03

Concurrent Multimodality Image Segmentation

I El Naqa*, K Bae, J Zheng, D Khullar, J Bradley, P Grigsby, D Low, J Deasy, Washington University St. Louis, St. Louis, MO

Purpose: Generally, in MRI, PET, and CT image datasets, more information is available for defining the target volume (or normal structures) than is used during the target segmentation. We introduce a method to take advantage of all the imaging information available for target segmentation, including multi-modality images or multiple image sets from the same modality. **Method and Materials:** We generalized the multi-valued level set deformable model (Chan et al., JVCI (2000) 11:130-141) for simultaneous 2D/3D segmentation/registration of multi-modality images consisting of a combination of PET, CT, or MR datasets. Information from multi modality image sets is combined to define the final target volume. The method was evaluated on three patient cases, including: a non-small cell lung cancer case with PET/CT, a cervix cancer case with PET/CT, and a prostate patient case with CT and MR. **Results:** In the case of the lung tumor the level set algorithm took 120 iterations for convergence, while in the case cervix tumor it converged after 30 iterations because the tumor has a deformed circular shape. In the prostate case, it took 50 iterations to converge and the results were made more sensitive to the shape prior information, because MR provides less gradient strength than PET. The computational time was on the order of few seconds in all cases. **Conclusion:** We a developed a new target segmentation algorithm which uses information simultaneously from multiple modalities. Our initial results indicate that the algorithm is promising and could provide physicians with a reliable contouring tool for lung, cervical, and prostate cancer.

This research was partially supported by NIH grant R01 CA85181 and a grant from TomoTherapy, Inc.

TU-C-ValA-04

Deformable Registration Using Regularization That Accommodates Local Tissue Rigidity

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Purpose: Existing methods for deformable image registration typically use homogeneous regularization to encourage global smoothness. Less work has been done to incorporate voxel-level tissue-specific elasticity information. Ignoring differences in elasticity can, however, result in non-physiological registrations, such as bone warping. We propose an approach to incorporate tissue rigidity information using a spatial variant regularization. **Method and Materials:** Regularized image registration algorithms estimate the deformation by minimizing a cost function, consisting of a dis-similarity metric and regularization. To account for tissue-type-dependent rigidity information, we incorporate into the cost function a non-rigidity penalty: an integral of stiffness index for local deformation weighted by spatial variant regularization factor depending on tissue type. For CT data, a simple monotonic increasing function of the CT number is used as a rigidity index for local tissue type. A necessary and sufficient condition for stiff local deformation is derived, and the local non-stiffness is measured by the deviation of local Jacobian from orthnormality using the Frobenius norm. Tensor B-Splines are used to parameterize the deformation field. A multi-resolution scheme and gradient-based approach are applied for optimization. Performance was accessed by registering 3D thorax CT-images obtained from different breathing phases. **Results:** Experiments with clinical data demonstrate higher accuracy for inhale-exhale thorax CT registration with the proposed approach. We observe comparable intensity match as the unregularized approaches, but more physiologically reasonable results with respect to different tissue types; in particular bone warping phenomena is eliminated in general. **Conclusion:** This work provides a way to incorporate tissue-type-dependent information into deformable registration framework with regularization design. Inference from image intensity avoids explicit segmentation, and is robust to partial volume effect. Our formulation based on local Jacobian and Frobenius norm provides analytical expression for the regularization and its derivative. More physiological results are achieved with minor computation expense.

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TU-C-ValA-05

Assessment of a Model-Based Deformable Image Registration Approach for Radiotherapy Planning

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Purpose: To assess the accuracy of a surface-based deformable image registration strategy as a function of the elasticity model for the integration of multi-modality imaging, image-guided radiation therapy, and quantification of geometrical change during and following therapy.

Method and Materials: A surface-model based deformable image registration system has been developed that enables quantitative description of geometrical change in multi-modal images. Based on the deformation of organ surfaces represented by triangular surface meshes, a volumetric deformation field is derived using different volumetric elasticity models (Thin-Plate Splines, Wendland functions, Elastic Body Splines) as alternatives to finite-element modeling. **Results:** The system was demonstrated on five liver cancer patients, ten prostate cancer patients, thorax in five healthy volunteers, and abdomen in five healthy volunteers. The accuracy of the system was assessed by tracking visible fiducials (bronchial bifurcations in the lung, vessel bifurcations in the liver, implanted gold markers in the prostate). The maximum displacements for lung, liver and prostate were 5.3 cm, 3.2 cm, and 1.8 cm respectively. The largest registration error (direction, mean ± standard deviation) for lung, liver and prostate were (inferior-superior, -0.21 ± 0.38 cm), (anterior-posterior, -0.09 ± 0.34 cm), and (left-right, 0.04 ± 0.38 cm) respectively, which was within the image resolution regardless of the deformation model. The computation time (2.7 GHz Intel Xeon) was on the order of seconds (e.g. 10 seconds for two prostate data sets), and image deformation results could be viewed at interactive speed (less than 1 second for 512x512 voxels). **Conclusion:** Surface-based deformable image registration enables the quantification of geometrical change in normal tissue and tumor with acceptable accuracy and speed.

TU-C-ValA-06

Quantifying the Properties and Accuracy of a Deformable Image Registration Algorithm for 4D Treatment Planning

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Purpose: A necessary tool to facilitate automated four-dimensional and adaptive radiotherapy planning is deformable image registration (DIR). The purpose of the current study was to quantify the accuracy of a DIR algorithm by comparing automatically transferred and manually segmented structures on 4DCT images. **Method and Materials:** 780 structures were manually segmented on thirteen patient 4DCT image sets each consisting of 10 respiratory phases. A large deformable diffeomorphic DIR algorithm, integrated with a commercial treatment planning system, was used to map each CT set from the inspiration respiratory phase CT image set respiratory phase images. The calculated displacement vector fields were used to deform and transfer structures defined on the inspiration CT to the other respiratory phase CT image sets. The manually and automatically segmented structures were compared using volumetric, displacement, and surface congruence metrics. **Results:** Deformation with respiration was observed for the lung tumor and normal tissues. This deformation was verified by examining the mapping of high contrast objects, such as the lungs and cord, between image sets. The auto- and manual methods showed similar trends, with a smaller difference observed between the GTVs than other structures. The auto-contoured structures were more consistent both in terms of centroid displacement and volume as a function

of respiratory phase than manual contours. 1.6% of the time, deficiencies of manual contouring has been detected using auto contouring. Image artifacts play a crucial role in auto contouring. **Conclusion:** An automated system is established to auto-contour structures starting from one 4DCT image phase to other 4DCT image phases. The auto-contoured structures generally agree with the manually drawn structures. However the auto-contoured structures are more consistent in trajectory and volume, and also highlighted some large errors in the manually drawn contours. Careful assessment is needed in the presence of 4DCT artifacts.

TU-C-ValA-07

Intra- and Inter-Modality Registration of Four-Dimensional (4D) Images

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Purpose: 4D-imaging techniques such as 4D-CT/MRI/PET reveal spatial and temporal details of patient's anatomy. Here we develop a 4D-4D registration method to utilize the 4D data acquired under different conditions or using different modalities. **Method:** A 4D input (model or reference) consists of a number of 3D sets of images, each representing the patient's anatomy at a phase point. When the patient's breathing pattern is repeatable, the task of 4D-4D matching is to find the appropriate 3D dataset in the model input for each phase in reference. Instead of exhaustively searching for the best match for each phase, a search algorithm was implemented, which can simultaneously find the matches for all phases with consideration of temporal relationship between the 3D image sets in the inputs. An interpolation scheme capable of deriving an image set based on two temporally adjacent 3D-datasets was implemented to deal with the situation where the discrete temporal points of the two inputs do not coincide. Digital phantom and patient studies were performed to illustrate the inter-/intra-modality 4D-4D registration technique. **Results:** In the phantom study where the optimal match is known, the proposed technique was able to reproduce the "ground truth" with high spatial fidelity (<1.5mm). In addition, the technique regenerated all deliberately introduced "missing" 3D images at different phase points in one of the inputs because of the temporal interpolation. In a registration of gated-MRI and 4DCT, the technique enabled us to optimally select the corresponding CT phase. The technique was also found useful for the registration of two sets of 4DCTs acquired at different time points. In this situation, a spatial accuracy of less than 2.5mm was achieved in all three cases. **Conclusions:** Automated 4D-4D registration can find the best possible spatio-temporal match between the two 4D datasets and may have significant implication for IGRT.

Joint Imaging/Therapy Scientific Session — Valencia B

Margin Assessment and Modeling of Inter-Fraction Motion

TU-C-ValB-01

Evaluation of Clinical Margins Via Simulation of Patient Setup Errors in 27 Prostate IMRT Plans

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Purpose: To evaluate: (i) the size of random and systematic setup errors that can be absorbed by 5mm CTV-to-PTV margins in prostate IMRT treatment plans; (ii) whether findings are consistent with published margin recipes; (iii) if shifting contours with respect to a static dose distribution accurately predicts dose coverage due to setup errors.

Method and Materials: 27 IMRT treatment plans with 5mm CTV-to-PTV margins were utilized. Random setup errors with standard deviations (SDs) of 1.5, 3 and 5mm were simulated by fluence convolution. Systematic errors with the same SDs were simulated using two methods: (a) shifting the isocenter and recomputing dose (isocenter shift), and (b) shifting patient contours with respect to the static dose distribution (contour shift). Maximum tolerated errors were evaluated such that 90% of plans had target coverage greater than a specified minimum. **Results:** For coverage criteria consistent with margin formulas, plans generated with a 5mm margin were able to absorb SDs >3mm. Most structures, including the prostate CTV, showed close agreement between isocenter and contour shift methods. Exceptions were the nodal CTV and small bowel. For 3mm SDs, contour vs isocenter shift estimates for the percent of plans with acceptable dose differed by >2% for the nodal CTV, and >7% for the small bowel. Contour shift small bowel D_{30} values differed from isocenter shift values by >120% for some simulated shifts. **Conclusion:** Published recipes require margins of 8-10mm for 3mm SDs. For the IMRT cases presented here, a 5mm margin would suffice. Approximating structure doses by shifting contours with respect to a static dose distribution was acceptable for most structures, but resulted in significant errors for the nodal CTV and small bowel doses for some shifts due to proximity to high dose gradients. (Work supported by NIH R01CA98524)

TU-C-ValB-02

Patient Specific Differences in Setup Error Variability and Its Effect On Treatment Margins in Fractioned Radiotherapy

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Purpose: It is often assumed that geometric error distributions in radiotherapy differ from patient to patient. It is however, problematic to substantiate this assumption because, generally, limited measurements are available per patient, giving a high uncertainty in the estimate of the standard deviation (SD). Our aim is to develop a simple method to estimate the true distribution variability based on statistical data analysis of a large patient population and to investigate the effect of detected variability on population based PTV-margins. **Method and Materials:** Setup error data of 470 prostate cancer patients (11 portal imaging measurements per patient, used for off-line corrections), were analyzed for random errors. The SD of the setup error was computed for each patient. The RMS-values of these numbers estimate the random uncertainty in the patient population. Next, the SD of the SD per patient is computed, containing the real distribution variability diluted by "measurement error in the SD" due to the limited number of samples. To estimate the true distribution variability, a correction is applied for this "measurement error". Finally, that margin was calculated that encloses the CTV with the 95% isodose for 90% of the population. **Results:** The true inter-patient variability is 26% of the SD, found after correcting for a "measurement error" of 18% (11 samples). Inter-patient distribution variability leads to larger PTV-margins, partly because the range of dose blurring becomes patient dependent. Assuming normality and the same SD variability in random and systematic errors, the margin for systematic errors increases from 2.5SD to 2.8SD, maintaining the same margin for random errors. **Conclusion:** Inter-patient distribution variability exists but only slightly exceeds its measurement error and it is therefore difficult to detect for individual patients. By grouping many patients, it can be detected. A variable distribution requires slightly larger margins than a homogenous one.

TU-C-ValB-03

The Dosimetric Impact of Intrafractional Motion On IMRT Treatment of Prostate Cancer

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Purpose: To quantify the dosimetric impact of intrafractional motion on reduced-margin IMRT treatments of prostate cancer. **Methods and Materials:** CT images were acquired immediately before and after a daily treatment for 46 prostate cancer patients. These CT sets were registered to the bony anatomy of the patient using an in-house 3D image registration software. To test the hypothesis that a 3-mm isotropic target margin would adequately cover the target over the duration of the treatment, an 8-field IMRT plan was designed on the pre-treatment CT and subsequently copied and re-calculated on the post-treatment CT. For convenience of comparison, dose plans were designed to receive a full course of treatment (75.6Gy). Dosimetric impact was assessed with comparisons of prostate, seminal vesicle (SV), rectum, and bladder volumes receiving several dose levels as well as the minimum and maximum doses to 0.1cc of the prostate and SV. Anatomic variations were also quantified. **Results:** Over the duration of one treatment fraction (21.4+/-5.5 minutes), there were systematic reductions in the volumes of the prostate and SV receiving the prescription dose (1.8 and 7.2 % respectively, P<0.001) as well as the minimum dose to 0.1cc of their volumes (2.1 and 6.4Gy, P<0.001). Of the 46 patients, 4 patients' prostates (91%) and 8 patients' SVs (83%) did not

maintain dose coverage above 70Gy. Rectal dose increased and dose to the percentage-volume of the bladder decreased at all dose levels. Rectal volume filling was correlated with a decrease in percentage-volume of the SV receiving 75.6, 70, and 60Gy (P<0.001, P<0.001, P=0.02). **Conclusion:** With a 3-mm intrafractional margin, a considerable percent of patients will not receive full dose coverage. The rectal volume increase during a treatment fraction has significant dosimetric impact on SV dose coverage and rectal sparing. Proactive immobilization of the rectum during treatment may be warranted.

TU-C-ValB-04

Margin-Less Prostate IMRT Plans, Directly Optimized for TCP and NTCP Including Geometric Uncertainties

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Purpose: To account for geometric uncertainties without the use of margins during IMRT planning such that optimal values are obtained for the population averaged TCP and NTCP functions. **Methods and materials:** A new method of computing cost functions was implemented within the IMRT planning tool Hyperion. Population-averaged values of biologic score functions (TCP_{pop} and $NTCP_{pop}$) are optimized, simulating random errors by blurring the dose, and systematic errors by displacing target and OARs relative to the dose distribution.
For 19 prostate (and seminal vesicle) patients, treatment plans for a five beam setup were created, optimising TCP_{pop} while constraining rectum $NTCP_{pop}$ and the maximum dose to the target. Gaussian distributions were used for the systematic and random errors (translations only, no attempt was made to model rotations or deformations). Since geometric uncertainties were accounted for within the cost functions, no CTV to PTV margin was used. For comparison, conventional plans were created using a CTV-to-PTV margin ($M=2.5\Sigma+0.7\sigma$) and a Simultaneous Integrated Boost (SIB) technique (68Gy to the above PTV, 78Gy to PTV_{boost} with 5mm margin, 0mm towards rectum). The resulting plans were evaluated using an independent tool that simulates the effects of geometric uncertainties. **Results:** Compared to conventional plans, our new technique reduced the planned dose to the rectum, while increasing the volume receiving 78Gy. We ensured that TCP_{pop} of the new technique was not smaller than for conventional techniques. The average rectum $NTCP_{pop}$ values were 14% (margin recipe), 8% (SIB), and 4% (new technique), for average TCP_{pop} values of 69%, 70%, and 71%. **Conclusions:** The computation of TCP and NTCP including knowledge of geometric uncertainties within the inverse IMRT optimization loop is feasible (less than 1 hour optimization time), and results in robust prostate treatment plans with an improved balance between local control and rectum toxicity.

TU-C-ValB-05

The Effects of Radiation Treatment On Respiration-Induced Lung Tumor Motion

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Purpose: The purpose of the present work is to assess the changes in size and respiration-induced motion of lung tumors resulting from radiation treatment. **Methods and Materials:** Six to ten four-dimensional computed tomography (4-DCT) image datasets were acquired for each of 5 stage-III non-small-cell lung cancer patients who received chemo-radiotherapy treatment over six weeks. Serial 4-D datasets were obtained each week. Gross tumor volumes (GTV) were outlined on each data set. Software tools in the radiation treatment planning system were used to calculate the volumes and centroids of the GTVs on the 0% (end-inspiration) and 50% (end-expiration) phase for each dataset. Interfractional changes in GTV location was assessed by registering corresponding phases of the datasets based on vertebral body landmarks and determining variations in the position of the GTV centroids relative to the landmarks. Forty-six scans including six primary tumors (involved nodal stations were not included) were analyzed. **Results:** The initial mean tumor volume was 53 cm^3 (range: 1 to 137cm^3). The interfractional changes in GTV position were predominantly in the superior-inferior direction with a mean magnitude of 3.4mm (range: 0.1 to 9.3mm). Overall tumor regression ranged from 20-71% (0% phase) and 15-70% (50% phase). As tumors shrunk, the magnitude of intrafractional GTV motion increased in the anterior-posterior and superior-inferior directions while remaining constant in the right-left direction. Reproducibility of the GTV-centroid position at the 50% phase, based on same-day repeat CT scans, was within 2 mm in each direction. **Conclusions:** Because of changes in tumor size and intrafractional tumor motion, care must be taken when reducing treatment portals based on explicit determination of the internal target volume (ITV). Repeat 4-DCT scans might be warranted during treatment.

TU-C-ValB-06

Intra-Fraction Motion of Immobilized Intra-Cranial and Extra-Cranial Patients Assessed by the CyberKnife Image-Guidance System

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Purpose: To quantify intra-fraction motion of immobilized intra-cranial and extra-cranial patients. The data can be used to optimise the intra-fraction imaging frequency and consequent patient set-up correction with the CyberKnife image-guidance system and to establish the required margins in the absence of such a system. **Method and Materials:** We analysed the intra-fraction motion of 21 intra-cranial patients, who were immobilized with a thermoplastic mask and 9 supine and 8 prone treated extra-cranial patients, who were immobilized with a vacuum bag. The motion was recorded by the CyberKnife image-guidance system. We analysed the intra-fraction motion by calculating the mean displacement with the standard deviation (SD) as a function of the time between kV X-ray localizations. For the three groups separately, we calculated the systematic (overall mean and SD) and the random displacement as a function of the imaging frequency. **Results:** For all patients, the overall mean displacement was below 0.5 mm (3D vector) over a period of 15 min and hardly increased. The SD of the systematic displacements increased linearly over time for all 3 patient groups. For intra-cranial, supine and prone treated patients, this SD increased to 0.5, 1.2, and 1.6 mm, respectively, in a period of 15 min. The random displacements for the prone treated patients were significantly higher than for the other groups, namely 1.3 mm (1 SD). This was most pronounced in the AP direction, suggesting that the larger intra-fraction motion was caused by respiratory motion. **Conclusions:** Repeated intra-fraction imaging and consequent patient set-up correction with an interval of less than 5 min adequately compensates for patient motion during treatment. In the absence of this procedure, intra-fraction motion has to be accounted for in the PTV margin.

TU-C-ValB-07

Evaluation of 4DRT: CT Acquisition and Gated Delivery System

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Introduction: Our objective was to characterize retrospectively acquired 4DCT data for prospective gated delivery, and the effects of gate length on beam energy stability, output constancy, and positional accuracy / inter-device constancy. **Materials and Methods:** A barometric sensor gated the Siemens Oncor linac and Siemens Sensation CT scanner. Respiratory motion of 20 mm at 15 bpm over a stationary jig was used to assess radio-opaque marker positions. Retrospective 4DCT reconstructions were obtained at 6 phases of inspiration and expiration, ranging from 0% to 100% by 20% intervals. The center of the pin was identified using 50% threshold values on the CT dataset. On the linac, gate windows of 1500, 850, 500, 350, 300, and 250 ms for the 12 phases were studied. Ion chambers were used to measure the beam energy and output stability at 10 cm and 20 cm in solid water simultaneously. Marker position during gated delivery was determined via film. Nine profiles, centered around the marker, were extracted for both the static and moving axes. The averages were smoothed, and the peak position and full-width-at-half-maximum (FWHM) were determined. The difference in FWHM along the static and moving axis is the intra-gate motion. **Results:** Dosimetry for gates >= 500 ms was excellent. Although the average energy was constant, gate length reduction from 500ms to 250 ms resulted in an energy standard deviation increase of 1-14%, an output constancy increase from 1.6% to 4.6%, and a 50% dose rate decrease. Mean discrepancies between marker position measured on CT and linac were 3 mm, with 8 mm maximum. **Conclusions:** Dosimetric characteristics of the linac are reasonable for gating windows ≥ 500 ms. Target position measured on retrospective

4DCT can introduce significant uncertainty for several phases of the respiratory cycle.

TU-C-ValB-08

Modeling Dose Delivery Accuracy of IMRT Head-And-Neck Cancer Treatment

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Purpose: To evaluate the impact of internal organ variations on IMRT treatments of head-and-neck cancers using different daily alignment techniques. **Method and Materials:** Eleven head-and-neck cancer patients were imaged twice weekly during their course of treatment (141 CT scans total) using an integrated CT-linear accelerator (EXaCT, Varian Oncology Systems). The clinical IMRT plans were copied onto the daily CT images. The plans were aligned with (1) the daily marked isocenter using three radio-opaque markers (BBs) and (2) bone alignment, using in-house software to align the cervical vertebrae. Daily dose distributions were mapped from the daily CT images onto the planning CT image with an in-house deformable image registration algorithm. Cumulative dose-volume histograms from the planning CT image were analyzed. **Results:** The differences in the clinical target volumes (CTV) gEUD between the planned and delivered doses (with BB or bone alignment) were typically ≤1Gy; therefore the differences in target coverage were most likely clinically insignificant. However, the alignment method did have a statistically significant impact on the percentage-volume of the CTV at the prescription dose. Neither BB alignment nor bone alignment maintained the planned coverage (average=98.2%), which was reduced to 95.6% with bone alignment (p=0.000) and 94.3% with BB alignment (p=0.000).

BB alignment significantly increased the average percentage-volume receiving ≥25Gy above the original plan for the ipsilateral (59.6% vs. 51.4%, p=0.003) and contralateral (42.0% vs. 36.4%, p=0.016) parotid glands. The parotid gland gEUD increased by more than 5Gy in 35% of BB alignments and 15% of bone alignments. However, there was no statistically significant difference between BB and bone alignments in parotid dose received. **Conclusions:** The differences in CTV coverage between bone and BB alignment were statistically significant but small. Bone alignment more closely reproduced the planned parotid dose than BB alignment, although both gave higher dose than the original plan.

TU-C-ValB-09

Setup Error Analysis of HN-IMRT Patients Using Electronic Portal Images and Cone-Beam CTs

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Purpose: It is important to monitor and correct patient setup during treatment course for head and neck IMRT because highly conformal dose distribution is sensitive to setup uncertainties. Setup for HN region is unstable because patient is usually uncomfortable under the mask and the flexible bony structures in the neck region. The purpose of this study is to analyze the setup errors during entire treatment course. These findings will help make appropriate corrective decisions. **Method and Materials:** Patients enrolled in our IMRT protocol are immobilized with a large thermoplastic mask attached to the MedTec IPPS. 2D analysis is accomplished by comparing electronic portal images to DRRs using in-house software. Systematic setup error exceeding 3mm is corrected. 3D analysis is performed by registering cone-beam CT to planning CT. Data from 21 patients with total 185 sessions were used. Correlation between 2D and 3D were analyzed. Time trend was analyzed for patients with daily CBCTs (4 patients with 131 scans total). **Results:** Good correlations were observed between 2D and 3D analyses with mean difference less than 1mm. Both methods showed that the mean of setup errors is under 1mm in all directions. The systematic and random errors were about 2mm. Margin of 5mm used in the planning seemed to be adequate based on empirical recipes. Time trend analysis shows that changes occurring during treatment course are significant for 3 (out of 4) patients. **Conclusion:** 2D and 3D analyses agree with each other, but 3D should be used whenever possible because it has the advantage of better image quality, lower imaging dose, and better software to interpret information. The difference is caused mainly from image quality and non-rigid bony motion. It may be necessary to redo the mask in the middle of treatment course to reduce overall setup error.

TU-C-ValB-10

Rectal Dose Variation in Image Guided Radiation Therapy of Prostate Cancer

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Purpose/Objective: To investigate the change in rectal dose during the treatment course for prostate IMRT with image-guidance. **Materials & Methods:** Ten prostate cancer patients treated with IMRT were included in this study. Each patient was administered an enema prior to CT- and MRI simulations. MR and CT were fused for target delineation. IMRT treatment planning was performed on the CT image. Prostate motion during the treatment course was corrected using a CT-on-Rails system. Rectal contours were generated on both simulation CT images and subsequent treatment CT images. IMRT plans were generated based on our clinical acceptance criterion. The subsequent treatment CT images for each patient from the CT-on-Rails system were used to recompute the patient dose distributions with the same leaf sequences used for treatment. The isocenter was shifted relative to the simulation CT, as required by the protocol, to ensure appropriate target coverage. The rectal doses based on the subsequent treatment CT were compared with the original doses planned on the simulation CT scans using our clinical acceptance criteria. **Results:** Based on ten patients with 84 treatment CT sets, 14% of the subsequent treatment dose distributions did not meet our criterion of V40 < 35% (V40=36%~50%), and 7% did not meet our criterion of V65<17% (V65=18%~36%). The inter-fractional rectal volume variation is significant for some patients. The minimum changes in rectum volume are between 31 and 39.8cc while the maximum changes are between 50.2 and 161.7 cc. In general, IMRT planning with an empty rectum results in better subsequent treatment dose distributions to the rectum. **Conclusions:** Due to the large inter-fractional variation of the rectal volume it is more favorable to plan prostate IMRT based on an empty rectum.

Professional Course — Room 230A

Medical Errors I

TU-C-230A-01

Introduction to Medical Errors and Implications

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There has developed, over the last few years, an increased awareness of the risks patient take when submitting themselves to medical procedures all of which are prone to errors. As a medical intervention, radiation therapy is no less susceptible to errors than any other branch of health care. Indeed in the case of radiation therapy both the consequences of errors and the number of patients affected can easily exceed those experienced elsewhere. A relatively small deviation from the prescription in either dose or volume irradiated can result in severe side effects or a failure to achieve the desired therapeutic outcome. Many patients are planned and/or treated on the same equipment facilitating the possible exposure to systematic effects.

In this presentation the current status of error prevention activities in radiation therapy will be reviewed. This will include initiatives in both North America and Europe. The AAPM has recently formed a working group to focus on this issue. In Europe, ESTRO is particularly active in this area through workshops, teaching courses and the ROSIS database. In addition there are less formal groups who are dealing with particular components of safety in radiation therapy.

If we are to live by the maxim “First, do no harm” then we need to do better than we are doing now. The degree of ambiguity in the available literature confounds interpretation in many cases. In particular we need to speak the same language when describing safety/quality issues. We need to have a metric for describing the severity of incidents in radiation therapy. One will be suggested for discussion. Ideally we should have a causal structure, which could be linked to a high level process map, for investigating incidents. With a causal structure we have a much better chance of learning from the actual and potential incidents which do occur. The learning component is one that we are particularly weak at. With a better understanding of the probability and severity of incidents we will make more informed decisions on the allocation of safety/quality resources.

Finally, patient safety in radiation therapy is too big to deal with effectively on an individual clinic basis. While local issues undoubtedly influence the local risk of incidents, we will be able to give our patients a far better guarantee of both a safe and effective treatment if we work together across professional and geographic boundaries. To do this we need a common taxonomy, a degree of commonality in causal analysis and a common commitment to effective learning strategies.

Learning Objectives:
1. To appreciate the current status of error reduction activities in radiation therapy.
2. To identify some of the limitations of current activities.
3. To consider approaches to improving error reduction strategies.

TU-C-230A-02

Error Analysis/reduction Philosophy/theory

T Pawlicki*, Stanford Univ School of Medicine, Stanford, CA

The purpose of this presentation is to discuss the philosophy and theory of error analysis and reduction. This talk will be equal parts conveyance of technical information and provocation to action on the important issue of medical errors. Although a somewhat obvious connection, we begin by providing a sound framework that relates errors and quality assurance. The scope of technical information within this presentation will be an attempt to wade through the myriad of theories and philosophy related to errors and quality, much of which is new to our field. For example, the JCAHO Lexicon describes quality as, "Designing a product or service as well as controlling its production so well that quality is inevitable." What does it actually mean to *control* a product or service? This will be described. The leadership of the AAPM has taken the ambitious step to change the emphasis of quality assurance from simply checking specifications to investigating processes via the new quality assurance task group (TG100). This is a significant and necessary paradigm shift in our approach to medical errors and quality that deserves a detailed discussion. An understanding of how to reduce errors and improve quality begins with an appreciation of two realities: 1) everything we do involves a process, and 2) every process has unavoidable variation. If one controls variation in a process, then one will reduce errors and improve quality. The implementation of process identification and control to clinical practice will be discussed in detail and by example where appropriate. Furthermore, there is a significant history of error reduction and quality research and this context will be maintained throughout the presentation. In addition to specific techniques of error analysis and reduction such as failure modes and effects analysis (FMEA), root cause analysis (RCA), pareto charts, fishbone diagrams and statistical process control (SPC) we will discuss the philosophies of define, measure, analyze, improve, control (DMAIC) and total quality management by the six-sigma approach.

Error analysis and reduction (and quality assurance in general) are built on a mature body of research from other fields. There is much work to do toward implementing these techniques in radiotherapy practices to minimize errors and optimize quality. There are no turn-key solutions to quality. As will be described, the business world has become fanatical about quality to stay competitive. Why should the medical world be any different with our patients' well-being at stake? Medical physicists, above anyone else in the typical department, have the analytical ability to understand and implement these techniques. We must accept the challenge and as a first step, future AAPM meetings should have a research session specific for quality, error analysis/reduction and cost analysis/reduction.

Therapy Scientific Session Room 224 A

IMRT Optimization

TU-C-224A-01

Fast Multifield Optimization of the Biological Effect in IMRT with Ion Beams

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Purpose: To investigate a new technique for multifield optimization of the biological effect (relative biological effectiveness times dose) for intensity modulated radiotherapy with scanned ion beams and to compare this method to an existing planning system for ions. **Method and Materials:** Our approach is based on the mixed irradiation formalism of the linear-quadratic model using dose averaged mean values of alpha and sqrt(beta). We employ a novel objective function to directly optimize the biological effect rather than the physical dose. It is based on constraints in biologically effective dose for targets and organs at risk in close analogy to inverse planning for photons. The required biological input data are reduced to a minimum and are completely independent from the optimization itself. They can be derived from any radiobiological model or even from directly measured data. The new optimization method is fully integrated into the inverse treatment planning tool KonRad. **Results:** Comparisons with the TRiP98 treatment planning code are shown for spread-out Bragg peaks as well as for three-dimensional treatment plans for carbon ions, where all fields are optimized separately. While the agreement between both planning systems is very good, the calculation time is substantially reduced in KonRad. By enabling the multifield optimization in KonRad, the quality of the treatment plans and the sparing of healthy tissues can be clearly improved, which is demonstrated on several examples. Depending on the number of beam spots used, typical optimization times are between 10 and 60 minutes. **Conclusion:** The proposed system offers complete and fast inverse treatment planning for ions. Simultaneous multifield optimization of the biological effect can considerably enhance the resulting plans since it makes the best use of all possible degrees of freedom. **Conflict of Interest:** Research sponsored by Siemens Medical Solutions corporation.

TU-C-224A-02

Aperture-Based Beam Delivery for Intensity Modulated Proton Therapy

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Purpose: Treatment planning for intensity modulated proton therapy (IMPT) has traditionally used an approach in which the intensity and energy for each beamlet are modulated, which requires high dose-rate beam scanning capabilities. The purpose of this work is to develop a new proton beam delivery method for IMPT without the need for high dose rate beam scanning. **Method and Materials:** In this study, an aperture-based method to deliver a uniform dose to a target volume has been investigated. For a target with a flat back surface, a broad proton beam is collimated with an aperture conformed to the cross-section of the target at a specific depth. The proton beam has a small energy spread to cover a 0.5-1.0 cm depth range. The mean energy and the weight of each proton beam are varied to produce a uniform dose distribution in the whole target volume. For an irregularly shaped target located in patient body, a compensator is used to provide equal beam path lengths to the back surface of the target. This will create an equivalent back surface for the target and then it can be treated in the same way as for the target with a flat back surface. A Fluka based Monte Carlo package has been used for dose calculation in aperture-based IMPT treatment planning. **Results:** We have tested aperture-based IMPT planning on a variety of patient cases. The results demonstrate that it can produce highly conformal dose distributions using only five to six apertures per beam direction. As compared with scanning beam delivery, our studies demonstrate that aperture-based beam delivery can result in a significant reduction in both the number of beam segments and the number of monitor units. **Conclusions:** Aperture-based IMPT optimization results in highly efficient treatment delivery while maintaining the dosimetric benefits of IMPT.

TU-C-224A-03

4D-Image-Guided Treatment Planning Optimization for Management of Organ Motion in Radiotherapy Planning

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The management of breathing-registered IMRT treatment planning is explored by direct incorporation of 4D images within the planning process. The movement of the voxels from one CT timeframe to another is ``tracked" and modeled. A timestamp for each voxel is used to specify its position throughout the breathing cycle. A single treatment model incorporates planning constraints throughout multiple time periods.

Robustness of the algorithm, plan quality, and potential clinical significance are evaluated.

4D-CT scans of lung/liver cancer patients were acquired with different breathing phases(phases 0-9, 0:full-inhale, 5:full-exhale), Three treatment planning strategies are performed and compared. 1)Standard planning with a static PTV based on a single selected phase (control). 2)The Internal Target Volume (ITV) approach, where ITV is defined as the union of CTVs in all breathing phases. 3)Single-stage-4D-image-guided planning, where within a single treatment optimization model, planning constraints are incorporated on each voxel for each phase throughout the multiple-phase period. Sophisticated computational optimization techniques are used to solve these models.

For both lung/liver cases, the static-PTV-plan results in unacceptable PTV-underdose. Compared to ITV-pamns, 4D-image-guided-plans offer good coverage and comparable min-PTV-dose; while in lung, it reduces normal-lung-mean-dose by 20%, heart-mean-dose by 20%, and esophagus-max-dose by 15%; and in liver, it reduces normal-liver mean-dose by 15% and other normal-tissue mean-dose by 20%, with improved PTV-conformity of 10%.

4D-Image-Guided treatment planning optimization can provide good PTV-coverage plans, improve PTV-underdose, and significantly reduce dose to organs-at-risk, especially those organs in the proximity of the tumor. Evidence of morbidity reduction to organs-at-risk is observed. The challenge involves the ability to solve a large-scale treatment planning problem. With sophisticated mathematical optimization modeling and computational strategies, such planning is possible and can be made available for clinical use. Clinical studies are needed to validate the importance of our approach to treatment outcome.

TU-C-224A-04

Simplifying Parameter Adjustment for Prostate IMRT Planning Using Sensitivity Analysis

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Purpose: To simplify the trial-and-error process of adjusting objective function parameters (e.g. weights, dose limits) in prostate IMRT planning, we present a feasibility study showing that an outer loop optimization over 6 automatically-identified sensitive parameters can quickly and automatically determine parameters that lead to a plan meeting the clinical requirements. **Method and Materials:** We apply statistical sensitivity analysis to quantify the effect of each hand-tunable parameter of the IMRT cost function on each clinical objective, automatically identifying those parameters with the strongest impact. Second, we globally optimize a plan quality score over the six most sensitive parameters in an outer loop to determine acceptable parameters, using a search algorithm based on multiscale random sampling. **Results:** Experiments on a 36-patient dataset showed that a clinically acceptable five-field 8640cGy prostate IMRT plan could be automatically determined in 35 minutes on the average in 87% of the cases. Compared to the plans from the planner's protocol default settings, the mean value of the minimum dose in PTV increased from 67.5% to 79.7%, and the mean value of PTV V95 coverage increased from 82.2% to 94.1%. The mean values of rectal wall V54%, rectal wall V87% and bladder wall V54% are 50.4%, 12.6% and 36.1%, respectively. The outer-loop-optimized plans met DVH constraints defining clinical acceptability and were comparable to manually-determined plans. Confining the parameter search to the sensitive parameter set greatly improves the quality and speed of the outer-loop optimization. **Conclusion:** The reduced-order outer-loop optimization can facilitate parameter selection for dose-volume-based IMRT objectives. It may also be applicable to other types of objective functions, and has the potential to ease the manual burden of IMRT planning in more complex sites (e.g. head and neck).

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TU-C-224A-05

Dosimetry Comparison of the Newly Implemented Multi-Criteria Optimization Tool for IMRT Planning

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Purpose: To apply a biological model based algorithm for acquiring optimized IMRT planning solutions. This interactive planning tool will help users to select the best available plans in the IMRT solution space.
Method and Materials: IMRT often is a time consuming iterative optimization process between evaluation of the dose distribution and redefinition of the object function. An IMRT planning optimization tool (Multi-Criteria Optimization, MCO™) has been introduced for non-clinical evaluation to acquire the best available solutions. Based on a Pareto's solution concept, this tool could search the solution space and offer users a limited set of deliverable IMRT plans. With this interactive process, users can set the target and critical structures dose constraints with the biological model (EUD) to obtain the best solution. We used Pinnacle system as the benchmark to compare the dosimetric gain from the MCO algorithm, DVH indicated excellent sparing with better PTV coverage is achievable from the MCO process in KonRad system.
Results: Dosimetric findings are summarized as 1) MCO optimization testing shows that much better dose distribution can be achieved compared to the current planning results (Fig. 1 and Fig. 2). Due to the confined solution space, the optimal results are easily achievable. 2) MCO with Pareto's approach is durable in the solution searching process. It is interactive with the graphical interface which the dose distribution along with the DVH can be compared simultaneously (Fig. 3). 3) IMRT dose optimization and summary based on the MCO methodology are very conceivable. With pre-calculated IMRT solutions, final results help users to select the best available plan from the solution domain in real time (Fig. 4). **Conclusion:** From this interactive MCO planning tool, we can calculate the best IMRT results in a very reasonable time frame. Human factors for determining an acceptable plan can be dramatically reduced.

TU-C-224A-06

Exploiting the Full Potential of MLC Based Aperture Optimization Through Collimator Rotation

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Purpose: To investigate the benefits of MLC rotation in Direct Aperture Optimization (DAO) inverse treatment planning. **Method and Materials:** An alternative to fluence based inverse planning is to optimize directly the leaf positions and field weights of MLC apertures. Here we introduce a new technique called Rotating Aperture Optimization (RAO) which is based on an extension of DAO. Our technique differs from existing aperture based IMRT techniques in that the MLC is rotated in between each aperture. Treatment plans are generated for 10 nasopharynx recurrence patients with and without MLC rotation for 5 mm and 1cm leaf width MLCs. A comparison study is performed between RAO and DAO in order to assess the benefits of RAO over and above those available with fixed collimator angle DAO. Film verification is also performed to evaluate the accuracy of fixed and rotated collimator aperture delivery. **Results:** An analysis of the final cost values and DVHs indicate that plans generated with RAO are as good as or better than DAO while maintaining a smaller number of apertures and MU than conventional IMRT. In particular, RAO with the 1cm leaf width MLC is able to produce better plans than DAO with the 1 cm leaf width MLC and plans that are equivalent to DAO with the higher resolution 5mm leaf width MLC. Film verification results show that RAO is less sensitive to tongue and groove effects than DAO. Although delivery time is increased due to the collimator rotation speed this is a mechanical limit that could be easily overcome. **Conclusion:** Our results indicate that RAO is able to provide superior dose distributions, particularly with larger (1 cm) leaf width MLCs, while maintaining the lower MU and number of apertures afforded by the direct aperture approach.
Conflict of Interest: Supported in part by Varian Medical Systems.

TU-C-224A-07

Multi-Objective IMRT Planning: A New Algorithm, with Clinical Examples

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Purpose: Intensity modulated radiation treatment planning for difficult cases is typically a time-consuming manual search for a plan which gives an acceptable tradeoff between tumor coverage and critical structure sparing. We develop a method to calculate the efficient tradeoff surface of a multi-objective IMRT inverse planning problem. This serves two purposes: to eliminate the time-consuming manual search process, and to provide the treatment planners with the complete tradeoff information, allowing them to make more informed decisions. **Method and Materials:** We formulate a linear multi-objective IMRT treatment planning problem, the solution of which is a set of Pareto optimal treatment plans. Since each Pareto optimal plan involves a lengthy optimization, it is prudent to represent the complete surface with as few points as possible. Given the current set of Pareto surface plans, we use geometric considerations to formulate the optimization problem which computes the next plan. In this way, plans are added to the Pareto database until the surface is well represented. **Results:** The algorithm is applied to two clinical cases. For the prostate case, we display a tradeoff between the prostate coverage, femoral head sparing, and rectal sparing. For the skull-based tumor, we display a tradeoff between tumor coverage, and the maximum doses of the chiasm, pituitary, and brainstem. **Conclusion:** We provide a method to efficiently generate Pareto surfaces for treatment planning, even when the number of organs to be traded off exceeds two or three. The method is applicable to any convex objective functions, including equivalent uniform dose, as well as the more standard quadratic penalty IMRT formulations. We expect that the clinical benefit of being able to visualize the tradeoff information – e.g. exactly how a decrease in critical structure dose degrades the tumor coverage – during the planning process will inspire a surge of research in this field.

TU-C-224A-08

A Scientific Comparison of Inverse Treatment Plan Quality Using a Convex Non-Linear Programming Model as a Function of Beam Quality and Beam Number

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Purpose: Recent advances in large scale fluence map optimizations for IMRT allow the use of large beam numbers that conform to the target to generate the desired target coverage while at the same time maintaining dose to critical organs below tolerance limits. Additionally, IMRT has effectively removed the need for high energy accelerator beams due to the excellent plan quality achievable with low beam quality. We investigate the diminishing returns in plan quality with increasing beam numbers and compare IMRT treatment planning of 6MV and ^{60}Co therapy dose models. **Method and Materials:** A convex non-linear model was used to compare the plan quality, from dose volume histograms and fluence maps, for three treatment sites (H & N, CNS and prostate) for a 6MV and ^{60}Co dose model. Plans were calculated for 5, 7, 9, 11, 17, 35 and 71 equidistant beam angles and quality assessed on target coverage ($R_{95\%} > R_{Rx}$) and organ sparing for each case. **Results:** Similar target coverage was achieved for ^{60}Co as with 6MV and equivalent organ sparing was also observed for all three sites. Increasing the number of beams provided some improvement in organ sparing while maintaining target coverage conditions. Dose calculation times increased linearly with beam number and FMO calculations increased by up to 900% between 5 and 71 beams. **Conclusion:** We have demonstrated that IMRT plan quality using a ^{60}Co dose model produces similar dose distributions to 6MV. We also show that plan quality does not show considerable improvement above 11 beams for IMRT and significant increases in the treatment planning times are observed extending the number of treatment beams to 71 beams.

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TU-C-224A-09

Implementation and Comparison of Several Proton IMRT Algorithms

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Purpose: To computationally compare the plan quality provided by 3 different intensity modulation proton therapy (IMPT) techniques: 3D modulation; 2.5D modulation; and distal edge tracking (DET) with optimization. Plan quality, problem size, and efficiency were assessed. **Method and Materials:** The dose calculation was based a finite sized beamlet model, which was 1x1 cm^2 at isocenter. The dose from each beamlet was the superposition/convolution of infinitesimal pencil beams falling within the beamlet. Ray tracing to each voxel was performed for each beamlet to find out the radiological depth to each voxel. In the 3D modulation algorithm, a stack of Bragg peaks were placed between the maximal and minimal radiological depths of targets passed by a beamlet with 2.5 mm spacing. The fluence of each Bragg peak was modulated independently by the optimizer. The placement of the Bragg peaks in the 2.5D algorithm was similar to the 3D algorithm, but the Bragg peaks belong to a beamlet were pre-optimized to make a spread out Bragg (SOBP) whose dose level was equal to the prescription dose of the target it passed. The weights of SOBPs were optimization variables. In the DET algorithm, the Bragg peaks were set at the distal edge of the targets. **Results:** The 3D algorithm could produce the best plan with least beams, but the data size was large. The DET was most efficient in dose calculation and fluence map optimization, its plan quality was fair. The advantage of the 2.5D algorithm was in its small data size and efficiency in fluency map optimization. **Conclusion:** An appropriate algorithm should be selected to meet the trade-off of plan quality versus computational and delivery efficiency.

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TU-C-224A-10

A Novel Neighborhood for Local Search and Simulated Annealing Methods in Beam Orientation Optimization in IMRT

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Purpose: To select quality coplanar solutions to the beam orientation optimization (BOO) problem in intensity-modulated radiation therapy (IMRT) treatment planning, and to demonstrate that high-quality treatment plans can be obtained using fewer beams than typically used in equi-spaced plans. **Method and Materials:** We consider the problem of obtaining quality 3- and 4-beam coplanar radiation treatment plans. Two methods to obtaining these solutions are tested: the simulated annealing (SA) algorithm, which provides a global approach to the problem, and the Add/Drop heuristic, which provides a locally optimal solution. In the algorithms, a novel neighborhood is considered wherein a beam's neighborhood consists of a number of beams adjacent to the current beam plus a number of beams adjacent to the parallel-opposed beam, which we call the "flip neighborhood". For the SA algorithm, several methods of obtaining neighboring solutions and different cooling schedules are considered. The algorithms were tested on six head-and-neck cases using coplanar beams on a 5° grid. The resulting treatment plans were compared to the 5- and 7-beam equi-spaced plans typically used in practice. **Results:** While the 3-beam treatment plans were poor in quality, the 4-beam treatment plans obtained using both the SA method and the Add/Drop heuristic had comparable or improved quality to the 5- and 7-beam equi-spaced plans typically used in head-and-neck treatment. **Conclusion:** For head-and-neck cases, quality plans with fewer beams than standard 5-7 beam treatment plans can be obtained if BOO is applied. We also show that although the flip neighborhood increases run time for the Add/Drop heuristic (the run-time of the simulated annealing algorithm is unchanged), it improves the FMO value for both the simulated annealing algorithm and the Add/Drop heuristic.

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Therapy Scientific Session Room 224 C
Clinical Measurements I

TU-C-224C-01
Investigation of Properties of a New Liquid Ionization Chamber
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Purpose: Liquid ionization chambers (LICs) have characteristics that can remedy some of the drawbacks of air-filled ionization chamber dosimetry: large sensitive volumes (i.e. low spatial resolution), fluence perturbations, and energy dependence over the clinical range of beam qualities. However, there are significant problems in liquid chambers. High ionization density and low ion mobility lead to high ion recombination rates. In this work, extensive experimental work has been performed to investigate properties of a new liquid chamber. This includes chamber stability over time, chamber reproducibility, and establishing recombination corrections. Methods and Materials: The new chamber is called the GLIC-03 (Guarded Liquid Ionization Chamber). The diameter of the collecting electrode is 1.5 mm and the plate separation is 0.4 mm, giving a sensitive volume of 0.7 mm^3. The dielectric liquid used is isooctane. We used the 18 MV beam of a Varian Clinac 21EX linear accelerator. The lowest pulse rate setting, 100 MU/min, was used in order to avoid incomplete collection of charge from one pulse before the arrival of the next. Measurements were taken in solid water at 15 cm depth, with various field sizes and SSDs. Boag's theory for general collection efficiency for parallel-plate gas ionization chambers, applied to isooctane in pulsed radiation, was used for recombination corrections. **Results:** The GLIC-03 response varied by less than 1% over 10 hours, and was reproducible within 1.5% of the mean over different liquid fills. The collection efficiency decreased with increasing dose per pulse due to general recombination of ions from a larger number of ionizing particle tracks. Recombination corrections were within 1% for low dose rates and high electric field strengths. **Conclusion:** The establishment of these characteristics in the present work allows us to perform accurate relative measurements in high gradient non-equilibrium fields as well as energy dependence investigations.

TU-C-224C-02
A Practical and Accurate 3D Dosimetry System for Radiation Therapy
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Purpose: At present, clinical dosimeters are limited to point or planar measurement, and hence do not provide the comprehensive 3D information ideal for verification of advanced delivery techniques. In this work we present a clinically viable 3D dosimetry system comprising a PRESAGE™ dosimeter with read out by an optical-CT scanner. **Method and Materials:** A novel solid dosimeter called PRESAGE™ has been developed which is composed of polyurethane polymer and radiochromic leuco dyes. PRESAGE™ exhibits a stable color change and hence optical density (OD) change when exposed to ionizing radiation. A PRESAGE™ cylinder of 16cm diameter x 11cm height was taken through the treatment planning process and a 5-field 6MV conformal radiation treatment was delivered by a Varian® linear accelerator. The radiation induced OD change was imaged in 3D by an optical-CT scanner and this measured distribution was then compared with the corresponding dose distribution calculated by the treatment planning system, as well as to independent measurement by GAFCHROMIC® film. Intercomparisons between the three dose distributions were made by superimposing isodose lines and calculating gamma maps (with criteria 4% dose difference and 4mm distance to agreement). **Results:** Given stable temperature and protection from exposure to incandescent light, the dose response of PRESAGE™ was observed to be robust to all aspects of the lab. The 3D dose distribution measured in PRESAGE™ showed good agreement with the calculated treatment plan (Eclipse) as well as the independent film measurement at all percent doses >30% (i.e. in regions further than 1cm from the wall). Gamma comparison shows that the PRESAGE™ measurement agrees with both the calculation in treatment plan and the film measurement within 4% dose difference and 4mm distance to agreement. **Conclusion:** This work presents the PRESAGE™/optical-CT combination as a practical 3D dosimetry system which can provide comprehensive quality assurance of advanced treatment techniques.

TU-C-224C-03
Dose Dependence of MOSFET Calibration Factor Between 30kV and Cobalt-60 Irradiation
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Purpose: To characterize the behavior of MOSFETs under radiation of various clinically relevant energies used in radiotherapy and radiology by evaluating its sensitivity or threshold voltage shift (CF) with regard to total integrated dose. **Method and Materials:** Seven p-type, duals bias MOSFETs from Thomson & Nielsen were investigated. They were exposed to four radiations sources: (1) ^{60}Co unit ($\langle E\rangle_\gamma$: 1.25 MeV), (2) ^{192}Ir HDR unit ($\langle E\rangle_\gamma$: 0.38 MeV), 30 kV beam ($\langle E\rangle_\gamma$: 14.8 keV) and (4) 150 kV beam ($\langle E\rangle_\gamma$: 70.1 keV). The MOSFET's sensitivity (CF_w) was evaluated at various moments in time and was calculated as the ratio of the measurement M_w (mV) over the estimated dose value D_w (cGy) both in water. ***Results:*** The sensitivity of MOSFET is express by their calibration factor (CF_w), and allows the user to associate the reading displayed by the device (mV) to a dose value (cGy). The CF_w value diminishes with increasing threshold voltage, especially for low energy radiation. It is stable for ^{60}Co irradiations, while it decreases of 6%, 5% and 15% for beam energies of ^{192}Ir, 150 kV and 30 kV respectively. This behavior is explained by an alteration of the effective field applied on the MOSFET (bias), caused by the accumulation of holes at the SiO_2 interface. It is strongly dependent on the radiation nature (LET) and particularly affects low x-ray energies. **Conclusions:** Those results are of major interest since, following the company recommendations to calibrate the device every 7 000 mV, it could lead to a significantly underestimated dose. A calibration of the device before every use and performing more than one measurement (thus using a mean dose value) should compensate the observed behavior.

TU-C-224C-04
Computed Radiography for Helical Tomotherapy Quality Assurance
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Purpose: To determine if a CR system that had been used for radiation therapy digital imaging since 2001 could also be used for IMRT quality assurance, and if the system could be used in helical tomotherapy quality assurance. **Methods and Materials:** The CR system used consisted of a desktop CR reader that utilizes storage phosphor plates, a 650 nm laser diode scanning beam source, and a high luminance light box for plate erasure. The CR plates are made of phosphor, coated with a photostimulable storage phosphor ($BaFBR:Eu^{2+}$). Three types of dose-to-response calibrations were performed 1.) Static square fields; 2.) An IMRT step-wedge; and 3.) A rotational helical tomotherapy delivery with concentric rings of known dose. All readings were taken with 6 MV beams. Like TLDs, some of the trapped charge carriers in the storage phosphor gradually decay with time. Because of the decay effect, it was important to determine the best time to wait between exposure and scanning. Five helical tomotherapy patients were selected as test cases for the CR dosimetry. Measurements were made in a cylindrical phantom with the CR plate and again with radiographic film. Calibration techniques #1, #2, and #3 were applied to the CR images to determine which was the most appropriate. Dose differences and gamma comparisons were made between the calculated and measured doses. **Results:** A time and field size dependence was observed. After comparing readings from different time intervals, ranging from one to twenty minutes, it was decided that four minutes was an optimal time to wait between exposure and scanning. Also, gamma for the CR images was significantly worse than the film images taken for the same patient. **Conclusions:** The field-size dependences, inconsistencies between calibration techniques, and plate decay make the CR system used in this study non-usable for IMRT dosimetry.

TU-C-224C-05
Energy Response of LiF:Mg,Ti Thermoluminescent Dosimeters to Moderately Filtered X-Ray Spectra in the Range of 20 to 250 KV Relative to 60Co
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Purpose: To use experimental methods to determine the response of LiF:Mg,Ti thermoluminescent dosimeters (TLDs) irradiated using moderately filtered (M-series) x-ray spectra in the energy range of 20 to 250 kV relative to the response to ^{60}Co photons. Also, to determine if LiF:Mg,Ti TLDs are intrinsically linear detectors (i.e. the response is proportional to energy imparted). **Method and Materials:** TLDs were irradiated to a known air kerma using the NIST traceable M-series x-ray beams, which were located at an Accredited Dosimetry Calibration Laboratory (ADCL), in the range of 20 to 250 kV. Using each x-ray beam, several sets of TLDs were irradiated to different air kerma levels to take into account any dose non-linearity. TLD response was then compared to that from several sets of TLDs irradiated at corresponding air kerma levels using ^{60}Co. The Monte Carlo code MCNP5 was used to correct for scatter from the holder and to determine the predicted/expected TLD response to the experimentally used x-ray beams. **Results:** The measured TLD energy response compared to the response to ^{60}Co shows a rapid decrease toward very low photon energies. This response dropped to approximately 0.90 at the lowest effective energy of 11.5 keV. The highest response was found to be 1.37 at an effective energy of 28.5 keV. The results showed poor agreement between measured energy response and calculations using the mass-energy absorption coefficients of pure LiF. A significant increase in measured response compared to calculated response was seen at effective energies higher then 25 keV. **Conclusion:** These results demonstrate that the measured energy response differs by up to 14% from Monte Carlo calculations and is highly dependent on the energy of the source. The results also suggest that LiF:Mg,Ti TLDs are not intrinsically linear with energy imparted.

TU-C-224C-06

Determination of TG-43U1 Recommended Parameters for Elongated RadioCoil™ Brachytherapy Sources 1.0 to 6.0 Cm in Length Using Experimental and Monte Carlo Simulation Techniques

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Purpose: In this project TG-43U1 recommended dosimetric characteristics of newly designed elongated RadioCoil™ brachytherapy sources(1 to 6)cm in length have been determined following experimental and Monte Carlo simulation techniques. Monte Carlo simulated dose profiles have also been calculated for sources 1 to 6cm in length. **Materials and Methods:** TG-43U1 recommended dosimetric characteristics (Λ, g(r), F(r,θ) ,ϕ_{an}) of RadioCoil™ sources have been determined using experimental(TLD) and Monte Carlo(MCNP5) simulation techniques. MCNP5 simulations were performed in spherical Solid Water™ and water phantoms 20cm in diameter for 10^8 histories. F(r,θ) of RadioCoil™ were determined for angles 0^o to 90^o for r≥L/2(where L=active length), and angles $5^o \leq \theta \leq 90^o$ for r≥L/2, with 5^o increment. TLD measurements were performed in solid Water™ using same geometric arrangement as that of Monte Carlo simulations. Measured and calculated dose profiles along the longitudinal axis of these sources were utilized to validate the dose calculation with commercially available treatment planning systems. **Results:** Results of these investigations indicate good agreement between MCNP5 simulated and TLD determined values for RadioCoil™ sources. Upon the good agreement between these two methodologies, confirming the accuracy of our simulation geometry, dosimetric parameters of these sources have been determined in liquid water for their clinical applications. It has been found that in order to achieve a good agreement between the treatment planning dose distribution, the F(r,θ) of these sources have to be determined at radial distances ranging from 0.5 to 5.0cm with 0.5cm increment and L/2 ±0.2cm. **Conclusion:** Dosimetric characteristics of newly designed RadioCoil™ have been determined following TG-43U1 recommendations using experimental and Monte Carlo simulation technique. In these determinations it has been found that the dose profile can be closely reproduced if the 2D anisotropy function is determined at 0.5 cm increments for radial distance ranging from 0.5 cm to 5cm, and L/2 ± 0.2cm.

TU-C-224C-07

A Comprehensive Dosimetric Protocol for the Cyberknife Radiosurgery System

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Purpose: To propose dosimetric guidelines specifically designed for the Cyberknife radiosurgery system. Non-availability of 10x10cm^2 field and use of small circular collimators (5mm to 60mm) pose serious problems, that have been faced in this study by means of 8 different detectors and Monte Carlo simulation. This work is oriented to measurement of total scatter factors ($S_{c,p}$) and to reference dosimetry, though indications will also be given in view of a comprehensive guideline. **Method and Materials:** PTW PinPoint 31014, Exradin A16 and T14P microchambers, TN 502RDM micromosfet, PTW 30008 diode and TM60003 diamond, MD55 and EBT radiochromic films were used to measure $S_{c,p}$. Monte Carlo simulations (BEAMnrc) were used to produce phase space descriptions at the exit plane of each collimator, to calculate: 1) theoretical $S_{c,p}$ values in water, and 2) correction factors to be applied to $S_{c,p}$ as measured by 5 detectors (PinPoint, A16, T14P, diode, diamond), obtained by simulating shape and chemical composition of each detector. BEAMnrc was also used to calculate stopping power ratios and chamber correction factors for the Cyberknife linac, to decide whether values of k_Q from the IAEA398 protocol could be applied without using a 10x10cm^2 field. **Results:** $S_{c,p}$ of the 5mm collimator as measured by simulated detectors averaged 0.653 -9%+14%. Variation for larger collimators was smaller. After Monte Carlo correction, $S_{c,p}$ of the 5mm collimator became 0.686 -2%+1%. Pure Monte Carlo calculation gave $S_{c,p}$=0.715 +/-1%. Calculation of correction factors showed that k_Q values for the investigated chambers could be chosen when using IAEA398, introducing +/-0.2% uncertainty. **Conclusion:** Pure Monte Carlo calculation gave higher values of $S_{c,p}$ compared to Monte Carlo-corrected measurement. The latter is to be preferred because correction factors are less sensitive to beam parameters than pure calculation of $S_{c,p}$. For determination of $S_{c,p}$ use of microchambers and Monte Carlo correction is recommended.

TU-C-224C-08

Design of a Small Radiation Facility for Radiobiology Studies

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Purpose: To design a small radiation facility for the partial- and fully -body irradiation of zebrafish embryos, cell cultures or any other small specimen used for radiobiology studies. **Method and Materials:** Zebrafish embryos larger than 1mm are the main animal to be irradiated in this micro-irradiator. Radiation is provided by a 50 kV photon beam from a miniature x-ray source, Xoft Inc., CA. Radiation field is delimited by a pinhole collimator. Diameter of the pinhole ranges from 0.5mm. A movable table and a video camera connected to a computer are used to position the specimen under the beam. Radiochromic film has been irradiated to test positional accuracy and dose distribution. **Results:** Coordinates of the position of the zebrafish with respect to the collimator are calculated from the image provided by the video camera and sent to the computer-controlled movable table to position the specimen under the beam. The micro-irradiator is totally portable and it can fit on the desktop. Positioning can be acquired with uncertainties of 50 µm in X and Y axis. Collimator design and portable shielding reduce both primary beam and scattering at safe radiation levels. Dose distribution is good enough for zebrafish irradiation and penumbra is in the order of 150µm ± 50µm. **Conclusion:** The designed micro-irradiator has attractive characteristics to facilitate zebrafish irradiation. Its portability and shielding simplicity make it adequate for any radiobiology laboratory. Its uncertainty in positioning is significantly smaller than zebrafish embryo size and radiation penumbra is acceptable for specimen larger than 1mm. This novel micro-irradiator design is appropriate for irradiation of partial-and fully- body zebrafish, cell cultures and any other small specimen used in radiobiology.

TU-C-224C-09

Radiation Characteristics of a Gated Fiber-Optic-Coupled Detector

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Purpose: To study the dosimetric characteristics of a gated fiber-optic-coupled detector for measuring absorbed dose from a linear accelerator. The favorable properties of these dosimeters are their superior spatial

resolution, real-time readout and potential as in-vivo dosimeters. In an application that takes advantage of its spatial resolution, small field tissue-phantom-ratio (TPRs) measurements from 0.6x0.6 to 2.0x2.0 cm^2 are obtained and compared to those measured with a diamond and diode detector. **Method and Materials:** The detector is a short length of Cu^{1+} fused doped quartz fiber coupled to a fiber-optic cable. It has an atomic number of about 10.8 with a density of 2.2 g/cm^3 and is 1 mm long with a diameter of 0.4 mm. The background signal generated by Cerenkov radiation and native fluorescence within the optical fiber during irradiation is separated from the detector luminescence via gating the signal with the radiation pulses from the accelerator. A linear accelerator provides mega-voltage photon and electron beams to investigate its energy response, dose rate dependence, dose linearity and reproducibility. **Results:** There is no measurable difference in the detector response between 6 and 18 MV photons. However, for electrons the dose response increases gradually by 7% from 6 to 20 MeV. Its dose rate response relative to a Farmer chamber exhibits a behavior similar to a diamond detector decreasing by about 4.5% from 0.8 to 10.7 Gy/min for both 6 and 18 MV photons. The measured response is linear from 0.2 to 10 Gy and its reproducibility is better than 2%. The small field TPR measurements are in good agreement with the diamond and diode detector. **Conclusion:** The dosimetric properties of this detector compare favorably with other radiation detectors, and its small size and optical interface make it potentially very useful for small field and in-vivo radiation dosimetry.

TU-C-224C-10

Transfer-Function Characterization of Heat Conduction in Water Calorimetry

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Purpose: To elaborate a transfer-function approach to characterizing the response of water calorimeters to abbreviated exposures in radiation beams. **Method and Materials:** Typical water calorimeters in use today derive from the original design of Domen, inferring absorbed dose from temperature measurements at a single point in a partially irradiated, extended volume. The success of the approach in deducing locally absorbed dose depends on heat transfer being "sufficiently" slow temporally and broad spatially compared to time- and space-scales of the measurement. In order to address these issues of "sufficiency" more quantitatively, we have undertaken an approach to the problem that assesses the impulse-response of the calorimeter to spatially and temporally localized radiation. The approach involves simple analytical models of heat conduction and finite-element methods that yield predictions of single-point temperature waveforms obtained from thermistors in a calorimeter. Output from the models is compared with experiment over wide variations in shutter period (30s-10,800s) and duty cycle (5%-50%). **Results:** Our findings show that heat conduction due to typical dose inhomogeneities within water calorimeters induces systematic variations in estimated dose that traditional data-analysis techniques ignore. Moreover, these variations do not diminish at smaller duty cycle, suggesting that they are intrinsic to the exposure time of the experiment, and not to the use of periodic exposure techniques. Essential features of the measurements are reproduced by both finite-element simulations and a simple analytical model. An RC-circuit analogue derived from the latter suggests that conduction phenomena with a spatially masked beam proceed by a multiplicity of times scales, ranging from seconds to hours, which contribute significantly to systematic variations in estimated dose. **Conclusions:** The variations of estimated absorbed dose described here suggest that a small systematic error (<1%) may affect existing standards measurements based on water calorimetry.

Imaging Scientific Session — Room 330 A

Image Segmentation and CAD

TU-D-330A-01

Computerized Lesion Detection On Breast MR Images

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Purpose: To develop a computerized lesion detection method for DCE-MRI breast images using the fuzzy c-means clustering algorithm. **Method:** Contrast-enhanced MR imaging is increasingly being incorporated into procedures for the screening of women at high risk of developing breast cancer. Such screening programs may potentially benefit from computer prompts that indicate potential lesion sites. In addition, analysis of other enhancing regions in the breast may reduce the number of false detections. Thus, we are developing an automated computerized lesion detection method based on the fuzzy c-means clustering algorithm. The proposed method consists of four stages: (1) Breast volume segmentation based on a volume growing method ; (2) Fuzzy c-means clustering analysis on voxel-based kinetics within the 4D breast image data (3D over time); (3) Voxel-by-voxel membership assignment to the most-enhancing categories; and (4) Connectivity & size criteria for eliminating some false-positive detections. Methods were evaluated by calculating detection sensitivity for malignant lesions, detection sensitivity for all lesions, and number of false-positive detections per breast volume for output from the most-enhancing kinetic categories. **Results:** Our preliminary studies are based on 20 MRI cases including 21 lesions (9 biopsy-proven malignant cases, 5 biopsy-proven benign cases; 6 cases without pathological proof). Based on computer-identified regions from the most enhancing membership category, the proposed method correctly detected 16 lesions, including all nine malignant ones. In addition, most of the benign cases fell into either the most-enhancing or second-most-enhancing categories. Preliminary results yielded, on average, 9 false-positive detections per breast volume, which will subsequently be input to the classifier stage that exams morphological and kinetic characteristics for false positive reduction. **Conclusion:** The preliminary results with our FCM-based computerized MRI lesion detection method are promising for potential use in breast cancer screening. **Conflict of Interest:** M.L.G. is a shareholder in R2 Technology, Inc.

TU-D-330A-02

A Search Model for Medical Image Interpretations

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Search involves locating lesions in images under conditions of uncertainty regarding the number and locations of lesions that may be present. A mathematical model of search is presented that applies to situations, as in the free-response paradigm, where on each image the number of normal regions that could be mistaken for lesions is unknown and the number of observer generated localizations of suspected regions (marks) is unpredictable. The search model is based on a two-stage descriptive model proposed in the literature according to which at the first stage the observer uses mainly peripheral vision to identify likely lesion candidates, and at the second stage the observer decides whether or not to report the candidates. The mathematical search model regards the unpredictable numbers of lesion and non-lesion localizations as random variables and models them via appropriate statistical distributions. The model has three parameters quantifying the perceived lesion signal-to-noise ratio, the observer's expertise at rejecting non-lesion locations and the observer' expertise at finding lesions. A figure-of-merit quantifying the observer's search performance is described, as well as ROC and FROC curves predicted by the search model. Finally, we describe a preliminary method for estimating the parameters of the search model from free-response data.

TU-D-330A-03

Comparison of Image Segmentation Algorithms On Digitized Mammograms and FFDM Images for CAD

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Purpose: To investigate lesion tumor segmentation methods for both digitized screen-film mammograms (DSF) and full-field digital mammography (FFDM). **Method and Materials:** Breast lesion segmentation methods are important in the overall image analysis for computer-aided diagnosis. Our initial development was performed on DSF, and we are currently evaluating our methods for use with FFDM. Three of our lesion segmentation methods were investigated using a database of 84 DFM and 287 FFDM cases including malignant and benign lesions. A region growing method utilizes the size and shape of the evolving lesion contour to determine the lesion margin. A radial gradient index (RGI) segmentation method uses a Gaussian constraint function to suppress the influence of distant pixels. Then for a series of contours returned by grey level thresholding, the contour with maximum RGI is chosen as the one that best delineates the lesion. A two-stage, region-based active contour

method minimizes an energy function based on the homogeneities inside and outside of the evolving contour. The minimization algorithm solves the Euler-Lagrange equation describing the contour evolution. Prior to the application of the active contour model, RGI segmentation is applied to delineate an initial contour closer to the lesion margin and estimate the effective background. The methods were compared to radiologist-delineated margins on both DSF and FFDM images using an area similarity metric. **Results:** At an overlap threshold of 0.3, the region growing, RGI, and two-stage methods correctly segmented 84%, 86% and 94% of the digitized screen-film lesions, and 81%, 83% and 88% of lesions on FFDM, respectively. **Conclusion:** Our results indicate that the two-stage method yields improved segmentation for both DSF and FFDM, and also that methods developed with DSF can be efficiently converted for use with FFDM. **Conflict of Interest:** MLG is a shareholder in R2 Technology, Inc.

TU-D-330A-04

Lung Cancer Screening Performance of Chest CT Images Using Frequency of Radiologists' Location Identifications

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The radiology exam reports and the computer-aided detection (CAD) findings on 26 low-dose CT, lung-cancer screening exams were compared to the findings of a reference database. The reference database was developed using 6 radiologists localizations of image features of concern. The radiologists were instructed to use a lax criterion for the identification of compact features that could be further evaluated for lung cancer. An unsupervised computer procedure using the distances between report locations determined which localizations were associated with the same image feature.

The reference database consisted of 609 findings of locations and their identification frequency. Forty two percent (257) of the reference database findings had a frequency of 2 or greater; these were considered positive finding using a lenient standard. The radiologist exam report identified 22% of the lenient standard findings, while the CAD system identified 16%. The database contained 50 findings (8%) using a stringent standard that the finding had to be reported on 5 or 6 occasions. The radiologist exam report identified 50% of the stringent standard findings, while the CAD system identified 40%. The radiology exam report had 6 findings not in the reference database.

Low dose CT, lung cancer screening exams contain numerous features of concern that could be further evaluated for lung cancer. The radiologist exam report missed 50% to 80% of these image features. The CAD system is unlikely improve the radiologists detection performance because it identified even fewer features of concern.

This study was made possible in part by equipment provided by R2 Technology and Siemens Medical.

TU-D-330A-05

CAD Scheme for Early Detection of Osteoporosis: Quantitative Analysis of Vertebral Fractures On Lateral Chest Radiographs

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Purpose: To develop a computerized method for detection of vertebral fractures on lateral chest radiographs and to help radiologists' diagnosis by using computer output as a "second opinion". **Method and Materials:** As an initial test, we examined our computerized method by using a small database (three fractured and three "normal" cases). Our computerized method was based on detection of upper and lower edges of vertebrae. The vertebral area was determined by using the posterior skinline. This vertebral area, the shape of which was curved in general, was straightened into the rectangle so that upper and lower edges of vertebrae would be oriented approximately horizontally. Horizontal-line components were enhanced by using a line-enhancement filter, and vertebral upper and lower edges on the line-enhanced image were detected by using a multiple thresholding technique followed by feature analysis. In some cases, straightening of vertebral area was inadequate. Therefore, second-straightening was provided by using left and right locations of detected vertebral edges. Vertebral heights were estimated from detected edges. Finally, fractured vertebrae were identified by estimated vertebral heights. For evaluation of detected edges by computer, three radiologists provided three vertebral edge locations (anterior, middle, and posterior) for vertebral edges, and their results were averaged as reference standard. **Results:** With our method, all of cases with fractured vertebrae were identified correctly with 0.16 false-positive detections per case. The locations of vertebral-edge points detected by computer were very close to the corresponding points determined by radiologists. Results on our computerized detection scheme will be presented for 49 cases (20 cases with fractured vertebrae and 29 normal cases). **Conclusions:** We developed a computerized scheme for detection of vertebral fractures on lateral chest radiographs. Our preliminary result indicates that vertebral fractures on lateral chest radiographs can be detected by computer. **Conflict of Interests:** KD: shareholder, R2 Technology Inc.

TU-D-330A-06

A Dynamic Motion Simulation with Heterogeneous Motion Constraints

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Purpose: Accurate radiation treatment of moving tumors is important for lung and low abdomen cancer patients. In this work, we have designed a tumor motion simulation system which provides a realistic simulation environment for advanced radiation treatment. The simulation can be used as a test bed for control algorithms of radiation dose delivery, motion prediction algorithms, and mechanical operation algorithms. It also provides us a better understanding of complicated tumor motion with incorporating different statistical analytical results. **Method and Materials:** We have defined motion rotation and translation in 2D space. The base motion is periodic patterns. Various constraints, such as amplitude fluctuation, velocity variation, frequency change, mechanical limitation, and system errors, have been considered in motion generation. The different variable can be predefined distribution, such as Gaussian distribution, or a probability distribution function from statistical analysis of real patient data. Motion prediction will be included in the simulation when only limited data is available. **Results:** We have designed the simulation based on statistical results of tumor motion from real patients and various constraints. A user friendly GUI interface with interactive control and nice visualization has been implemented. Several simulation algorithms have been implemented with different constraints. Intensive performance evaluation has been tested. The results show that our simulation system have produced simulated motion very similar to real tumor motion. **Conclusion:** Our simulation system provides a user friendly, interactive GUI interface for tumor respiratory motion simulation. The simulation algorithms considered various constrains in real treatment conditions. The simulation is valuable to understand tumor motion and is a good test bed for improved effectiveness in image guided radiation treatment. We will integrate our simulation in to a 2D phantom design.

TU-D-330A-07

A Fast Pseudo-1D Active Contour for Medical Image Segmentation

W Sensakovic*, S Armato, A Starkey, The University of Chicago, Chicago, IL

Purpose: A snake (active contour) is a deformable curve used in medical image processing to localize region boundaries. The time required for snake convergence to a solution is lengthened by increased data set size and complex external energy field computations. A new gradient vector flow (GVF) snake algorithm was developed to increase the convergence speed of the conventional GVF snake algorithm. **Method and Materials:** The new algorithm reformulates a 2D closed curve to a pseudo-1D open curve. This transformation reduces the solution search space and the area for external energy field computation. Further, curve deformations are restricted to one dimension, thus reducing the complexity for both deformation and external field computation. A binary 512x512 test image was created and the algorithms were run using each of three initializations. Additionally, both algorithms were applied to a 512x512 thoracic CT section. **Results:** The new algorithm, on average, converged to a solution for the binary image in 11.1s compared with 14.6s for the conventional algorithm (24% improvement). The greatest gains were seen in the GVF calculation where the mean reduction in time for GVF calculation alone was 2.9s (32% improvement). The time for contour fitting was also consistently decreased, with a mean reduction for fitting of 0.6s (11%

improvement). The new algorithm on average converged to a solution for the CT section in 4.01s compared with 7.15s for the conventional algorithm (44% improvement). Area-of-overlap measures for the contours generated by both algorithms exceeded 0.97 for both binary and CT test images. **Conclusion:** A new active contour algorithm was developed, and a consistent speed improvement over the conventional algorithm was measured. This new algorithm is compatible with other optimization techniques and shows potential for processing large medical image data sets. **Conflict of Interest:** S.G.A shareholder R2 Technology, Inc.

TU-D-330A-08

Information-Theoretic CAD System in Mammography: Investigation of An Entropy-Based Indexing Scheme for Improved Computational Efficiency and Robust Performance

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Purpose: We previously presented a Knowledge-Based Computer Assisted Detection (KB-CAD) system for the detection of mammographic masses based on information theoretic similarity measures. The purpose of this study is to integrate an entropy-based indexing strategy that improves the speed of analysis without compromising the diagnostic performance of the system. **Materials and Methods:** The KB-CAD system is designed to compare a query mammographic region with mammographic templates of known ground truth stored in the knowledge databank. The system utilizes normalized mutual information (NMI) as the similarity measure. Previous studies showed that the system's diagnostic performance consistently improves as the knowledge databank increases. However, comparing each query to every template stored in the databank becomes computationally impractical. To address this concern, we implemented an entropy-based indexing scheme. Instead of comparing the query with the whole knowledge databank, we restrict the comparisons to those stored templates that are most relevant or informative. Only those templates are retrieved for more detailed analysis using the NMI similarity measure. Image entropy was used to determine the level of information or relevance for each available template. **Results:** We used a database of 2,318 mammographic regions (905 masses, 1,413 normal) extracted from the Digital Database of Screening Mammography (DDSM). Based on a leave-one-out sampling scheme, different clustering implementations of the entropy-based indexing scheme were investigated. Using entropy-based indexing, the KB-CAD system achieved the same performance (ROC area index Az=0.91±0.01 for malignant masses) using only a subset of 600 templates from the knowledge databank (compared to the full set of 2,317 available templates). **Conclusion:** This study showed that to sustain detection performance while maintaining computational efficiency, an optimized subset of relevant templates could be determined using a sophisticated entropy-based indexing strategy.

Conflict of Interest: This work was supported in part by the National Cancer Institute under grant R01 CA101911.

Imaging Symposium Room 330 D
Molecular Imaging II: Clinical and Pre-Clinical Applications

TU-D-330D-01

Molecular Imaging II - Applications

J Hazle*[1], L Clarke*[2], E Jackson*[1], J Humm*[3], (1) UT M.D. Anderson Cancer Center, Houston, TX, (2) National Cancer Institute, Bethesda, MD, (3) Memorial Sloan-Kettering Cancer Center, New York, NY

Day two of the Molecular Imaging Symposium (MI-2) will focus on the applications of molecular imaging in small animals and humans. The session will begin with a discussion of a recent trans-agency announcement that addresses molecular imaging as a biomarker for drug response (DHHS *New Federal Health Initiative to Improve Cancer Therapy*). Opportunities for imaging physicists to engage in the development of physical performance standards for dual modality imaging platforms (anatomical and molecular imaging) during the course of therapy treatment will be discussed. Similarly the development of standardized methods to evaluate change analysis tools will be addressed. A case for creation of a new AAPM task group to address this topic will be presented. The following links are of interest:

http://www.fda.gov/oc/mous/domestic/FDA-NCI-CMS.html
http://www.nist.gov/public_affairs/factsheet/bioimaging.htm
http://imaging.nci.nih.gov/i3/

The second lecture will review the clinical research use of existing contrast agents in dynamic contrast MRI for early assessment of therapy-induced microvascular changes, pre-clinical use of novel high molecular weight and/or targeted or enzymatically activated MR contrast agents, endogenous contrast agent techniques, such a blood oxygen level dependent (BOLD), for assessing changes in tissue oxygenation, and other techniques for assessing treatment response or improving lesion characterization, including quantitative diffusion and spectroscopy techniques.

The session will conclude with an introduction of the new combined modality instrumentation now available in PET/CT and SPECT/CT, discuss clinical examples of radiotracers that are being used in oncologic imaging (FDG, amino acids, peptide, hormones, antibodies, cell proliferation and hypoxia tracers), techniques to evaluate whether radiotracers actually localize at the intended site (i.e., autoradiographic correlation with tumor immunohistochemistry in rodent models and on clinical biopsy tissue), and the use of functional images to determine features of tumor biology, to monitor treatment response, and for radiotherapy treatment planning.

Joint Imaging/Therapy Symposium Valencia B
Tomographic Guidance of Radiotherapy Procedures

TU-D-ValB-01

Mega-Voltage Cone-Beam Computerized Tomography

J Pouliot*, UC San Francisco, San Francisco, CA

Mega-Voltage Cone-Beam Computed Tomography (MVCBCT) systems have been in clinical use at UCSF since February 2005. This lecture will provide a general description of the MVCBCT system, image acquisition, reconstruction and registration. The practical clinical applications as well as the guidance strategies will be presented through a number case studies including the following anatomical sites; head&neck, lung, spine, prostate and pelvic sites.

Educational Objectives

1. Understand the basics concepts of MV Cone-Beam CT imaging
2. Understand the range of clinical applications made possible by MVCBCT in the following categories:
   a. Patient and organ positioning
   b. Monitoring of anatomical changes and tumor dose response
   c. Tomosythesis
   d. Dosimetric impact
   e. Dose planning in presence of CT non-compatible objects
   f. Brachytherapy
   g. Dose-guided radiation therapy (DGRT).

This work was supported by Siemens Oncology Care Systems

TU-D-ValB-02

KV Tomographic Image Guided Radiotherapy

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Purpose: To account for geometrical uncertainties during radiotherapy, safety margins are applied. In many cases, these margins overlap organs at risk thereby limiting dose escalation. The aim of image-guided radiotherapy is to improve the accuracy by imaging tumor and critical structures on the machine just prior to irradiation. NKI collaborated in the development of a kV cone beam CT guided accelerator. **Method and Materials:** The chosen imaging dose is 3 cGy for prostate, 1 cGy for head and 2 cGy for lung, 4D scanning. The availability of high quality tomographic images and automatic image registration on the machine leads to many new clinical applications, such as high precision hypofractionated treatments of brain metastases and solitary long tumors with on-line tumor position corrections. Adaptive radiotherapy (ART) of prostate cancer is

now also in routine use. We adapt to the average prostate and rectum using cone beam scans made during the first week of treatment. **Results:** The prostate is located automatically in 85% of prostate scans. Even though we use laxatives, the main confounding factor is short-term mobility due to moving gas that causes streak artifacts in the CT reconstructions. Our ART protocol allows reducing the margin from 10 to 7 mm. Patient localization with 1 mm accuracy (bony anatomy) is easily achieved with the current equipment. Pre- and post-treatment scans demonstrate negligible motion of about 0.5 mm SD, both for brain and bladder cancer patients. **Conclusion:** The availability of cone beam CT on the linear accelerator makes ART very efficient and more accurate, since problem duplicating the setup on the CT scanner are avoided. For all image-guided protocols, the residual uncertainties need to be taken into account, and the safe level of margin reduction evaluated. In conclusion, kV cone beam CT guided radiotherapy is now very much a clinical reality.

Learning Objectives:
1. Understand strengths and weaknesses of kV cone beam CT guided radiotherapy
2. Understand which clinical protocols are most suitable for this technique
3. Understand the necessity of careful uncertainty analysis and margin selection, especially with image guidance

This research was partially sponsored by Elekta Oncology Systems

TU-D-ValB-03

MR-Guided Mechanically Assisted Interventions

G Fichtinger*, Johns Hopkins Univ, Baltimore, MD

Magnetic Resonance Imaging (MRI) has become the gold standard in the imaging of many soft tissues, osseous and joint conditions, but to date there has been limited success in harnessing this excellent imaging modality for interventional procedures. MRI is an ideal interventional guidance modality: it provides real-time high-resolution images at arbitrary direction and is able to monitor therapeutic agents, surgical tools, biomechanical tissue properties, and physiological function. At the same time, MRI poses formidable engineering challenges by limited access to the patient and a strong magnetic field that prevents the use of conventional materials and electronic equipment. Currently, no exigent technical solution exists to assist MRI-guided needle placement procedures in an accurate, simple, and economical manner.

A wide variety of procedures may be performed on open magnets but the trend is to use high field closed magnets, mainly because of improved imaging quality and wider availability of pulse sequences. The higher the field the higher the SNR and the higher SNR can be used to improve spatial and temporal resolution and can make techniques like temperature or flow sensitive imaging, functional brain MRI, diffusion imaging or MR spectroscopy more useful. Considering these trends, we believe that the use of conventional high-field closed MRI scanners for guidance will allow more successful dissemination of MR-guided techniques to radiology facilities throughout the country and eventually beyond.

The talk will survey major trends and achievements in MR compatible interventional robotics, and present specific research projects and results currently in progress at the Johns Hopkins University and collaborators.

Professional Panel — Room 230A

CRCPD Suggested State Regulations

TU-D-230A-01

Panel: Review and Discussion of CRCPD Suggested State Regulations for QA

D Gilley*[1], J Winston*[2], M Martin*[3], G White*[4], (1) CRCPD Liaison to the AAPM, State of Florida, Tallahassee, FL, (2) CRCPD, Northwest Regional Office, Meadville, PA, (3) Therapy Physics, Inc., Bellflower, CA, (4) Colorado Associates in Medical Phys, Colorado Springs, CO

The Conference of Radiation Program Directors (CRCPD) develops Suggested State Regulations (SSRs) for use by the states in generating state regulations dealing with all aspects of the use of radioactive materials. The SSRs cover all areas of medical use of radioactive materials, whether regulated by the Nuclear Regulatory Commission or not. SSRs also address sources of x-ray and non-ionizing radiation. This Panel will discuss the SSR process, membership on SSR committees and the use of referencing other documents as standards of practice such as AAPM Task Group reports.

Therapy Scientific Session — Room 224 C

Monte Carlo Methods

TU-D-224C-01

Effects of Choice of the MLC Material On Neutron Dose Equivalent Outside of the Treatment Field in Proton Therapy

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Purpose: To determine the effects of choice of MLC material on neutron dose equivalent outside of the treatment field in proton therapy. **Method and Materials:** A four-dimensional GEANT4 Monte Carlo simulation of a commercially available proton therapy nozzle has been used to calculate the ratio of neutron dose equivalent to therapeutic proton absorbed dose (H_N/D_P). H_N/D_P varies significantly with proton beam energy, materials used in the nozzle, treatment technique, and range modulation. Technical specifications of the nozzle have been provided by the vendor. Lateral beam spreading is achieved primarily by binary pre-scatterer foils and a double contoured scatterer. Modulation is generated by a stepped propeller positioned at nozzle entrance, and pre-collimation is done by nickel inserts. A preliminary design of a multi-leaf collimator has been added to the simulation, providing final collimation. Four different data sets have been generated, each one corresponding to a different MLC composition: tungsten, brass, iron and stainless steel. **Results:** A 200 MeV proton beam is used in order to produce a large circular treatment field with a 10 cm radius, a depth of penetration of approximately 22 cm, and an SOBP width of 10 cm. Neutron dose equivalents are calculated outside the treatment field at three distances from isocenter: 15 cm, 25 cm, and 47 cm (along beam direction). The highest H_N/D_P ratios are calculated for tungsten, and vary from 10 mSv/Gy at a distance of 15 cm off axis, to 0.7 mSv/Gy at 47.5cm off axis. Corresponding H_N/D_P ratios for stainless steel are 6.93 mSv/Gy and 0.46 mSv/Gy, representing the lowest calculated values. **Conclusion:** A steel MLC produces, on average, 45% less secondary neutron dose deposit compared to a tungsten MLC. The result indicates potential for dose reduction in proton therapy when a steel collimator is used instead of a tungsten collimator.

TU-D-224C-02

Monte Carlo Direct Aperture Optimization (MC-DAO) for IMRT

A M Bergman*[1, 2], K Bush[3], M Milette[1, 2], I A Popescu[1, 3], K Otto[1], C Duzenli[1, 2], (1) British Columbia Cancer Agency, Vancouver, CA (2) University of British Columbia, Vancouver, CA (3) University of Victoria, Victoria, CA

Purpose: To improve the accuracy/efficiency of IMRT planning by combining Monte Carlo (MC) dose calculation with direct aperture optimization (DAO). **Method and Materials:** A 6 MV beam arrangement is applied to an IMRT phantom and patient examples. A phase space is calculated below the secondary jaws of a virtual Varian 21EX linac by MC simulation (BEAMnrc code (NRC, Canada)). The phase space is subdivided into 2.5x5.0 mm^2 beamlets and the dose distribution from each beamlet is calculated to organs-of-interest within the patient/phantom using DOSXYZnrc. This information is input into DAO inverse planning software. The DAO includes multileaf collimator transmission and leaf motion limitations as it modifies the shape/weight of the treatment apertures. The optimized leaf sequence requires no additional leaf motion calculation step. A final forward MC dose calculation is performed. The MC doses are verified with ion chamber and film measurement. MC-DAO is applied to a difficult phantom geometry, namely a c-shaped target with embedded organ-at-risk located directly adjacent to a 5.0cm-thick air slab. Clinical sites include nasopharynx and lung. **Results:** The MC optimization allows for accurate modeling of the electronic disequilibrium introduced by the air cavities. For the phantom example, MC reveals that the plan optimized with a pencil beam (PB) algorithm fails to provide adequate coverage to the PTV close to the air cavity, whereas the MC-DAO plan demonstrates adequate coverage. For the nasopharynx, the PB plan showed errors during ion chamber/film verification, probably due to the

small (~5x4 cm^2) fields whereas the MC-DAO plan showed good agreement. The reduction in monitor units for MC-DAO plans is 20 – 40% compared to a commercial fluence-based (PB) treatment planning system. **Conclusion:** MC simulation generates accurate input data for IMRT inverse treatment planning in difficult-to-calculate regions. The addition of DAO results in a more efficient treatment plan delivery.

TU-D-224C-03

TG-43U1 Brachytherapy Dosimetry Parameters for Virtual, Unfiltered Sources

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Purpose: Underlying brachytherapy dosimetry characteristics for ^{137}Cs, ^{125}I, ^{192}Ir, ^{103}Pd, and ^{169}Yb were examined using Monte Carlo methods. Sources were modeled as unencapsulated point or line sources in liquid water to negate source-specific effects of materials and construction. Importance of phantom size (R), radiation transport mode, phantom material, and volume averaging were studied. **Method and Materials:** Radiation transport simulations were performed with MCNP5 using the most recent photon cross-section libraries. The AAPM TG-43U1 brachytherapy dosimetry formalism was employed and extended to radionuclides with $E_{AVG} > 50$ keV. Radiation spectra were taken from the National Nuclear Data Center and compared to those commonly referenced. Enough photon histories were simulated to maintain statistical uncertainties < 1%. **Results and Discussion:** For non-infinite media, g(r) was found to degrade as r approached R, the phantom radius, and MCNP5 results were in agreement with those published using GEANT4. Dosimetry parameters calculated using coupled photon-electron radiation transport simulations did not differ significantly from those using photon transport only. Low-energy radionuclides ^{125}I and ^{103}Pd were sensitive to phantom material with up to a factor of 1.4 and 2, respectively, between tissue-equivalent materials and water at r = 9 cm. In comparison, high-energy photons from ^{137}Cs, ^{192}Ir, and ^{169}Yb demonstrated ± 5% differences between water and tissue-substitutes at r = 20 cm. Similarly, volume-averaging effects were found to be more significant for low-energy radionuclides. When modeling line sources with $L \leq 0.5$ cm, the 2-D anisotropy function was largely within ± 0.5% of unity for ^{137}Cs, ^{125}I, and ^{192}Ir. However, an energy and geometry effect was noted for ^{103}Pd and ^{169}Yb, with $F(0.5,0^o)$ = 1.05 and 0.98, respectively, for L = 0.5 cm. Additional radiation transport calculations using mono-energetic photons showed energy-dependent variations in $F(r,\theta)$ as a function of effective length and θ.

TU-D-224C-04

A Monte Carlo Post-Implant Prostate Dosimetry Study : Interseed Attenuation, Tissue Composition, and Calcification

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Purpose: To use an automated Monte Carlo (MC) code to perform a clinical dosimetry study that includes 18 post-implant prostate brachytherapy cases. The interseed attenuation and the impact of tissue compositions are specifically investigated. **Method and Materials:** A MC technique is used to simulate the post-implant dosimetry for voxelized patients. For a typical patient, 200,000 voxels are stacked to generate the realistic anatomy. For each voxel, the density is set by the Hounsfield Units (HU) from the computed tomography data and the elemental composition is set according to the radiation oncologist's contours. Between 180 and 320 different materials (prostate tissue, muscle, rectum tissue, bladder tissue, calcification, adipose tissue, and various mixtures) are utilized for each patient. Data (HU, seed positions, and contours) is input into the MC program through the DICOM-RT protocol. Several MC simulations are performed in order to study different elements: interseed attenuation, impact of inter-organ tissue composition, prostate composition, and specifically calcifications inside the prostate. **Results:** The interseed attenuation level is 3.9±1.5% for the D_{90} CTV parameter. The effect on organs at risk is an average decrease of 0.2 cm^3 for the V_{100} parameter in both rectum and bladder. For the 18 clinical cases, the comparison between the TG-43 based dosimetry and the complete MC simulation leads to average differences of 12±3 Gy for the D_{90} CTV parameter. If localized and/or diffuse calcifications are incorporated into the prostate tissue, differences of up to 14 Gy are added. **Conclusion:** The overall difference between the clinically approved TG-43 based calculations and MC simulations can reach non-negligible levels. Including the calcifications in the prostate can lead to important dosimetry differences. However, the presence of calcification is difficult to establish with traditional CT data.

TU-D-224C-05

Validation of a Linear Accelerator Source Model and Commissioning Process for Routine Clinical Monte Carlo Calculations

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Purpose: Many source models for Monte Carlo treatment planning include parameters which are difficult or ambiguous to determine. We developed and tested a straightforward source model and commissioning process for clinical Monte Carlo calculations. **Method and Materials:** Our commissioning process of fitting treatment planning system data includes fitting the photon spectrum, electron contamination, penumbra fluence blurring, jaw leakage, and the flattening filter effect. The energy spectrum is fit using a modified Fatigue Life Distribution multiplied by a Fermi. Electron contamination is modeled separately an exponential function, as suggested by Fippel. Penumbral blurring is modeled using a Gaussian filter. Leakage radiation is modeled as a low-intensity wide-field monoenergetic source. The flattening filter effect is modeled by multiplying the optimized fluence by a Gaussian reduction. The penumbra and the flattening filter are applied to the fluence map. We tested our methodology on doses produced by a Varian accelerator for 6 MV and 18 MV photons and 5x5, 10x10, and 20x20 cm^2 field sizes. **Results:** We found that nine published photon spectra of Varian, Eleckta, and Siemens linear accelerators, ranging in energy from 4 MV to 25 MV could be modeled by the Fatigue Life Distribution with a Fermi cutoff. The agreement between the TPS doses and the commissioned MC doses were within 2%. Off-axis energy spectrum softening was unneeded. **Conclusion:** We have developed a straightforward, yet flexible source modeling system. The commissioning process affords a high-degree of automation with an unambiguous determination of the relevant parameters. Commissioning of clinical Monte Carlo treatment planning systems is facilitated by using a source model which is only as complicated as necessary to accurately simulates dose distributions.

Conflict of Interest:
This research was partially supported by NIH grant R01 CA90445 and a grant from Sun Nuclear, Corp.

TU-D-224C-06

Simulation of Si Diode Response in Clinical Electron Beams

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Purpose: To study the response of a silicon diode in clinical electron beams by using the EGSnrc Monte Carlo code. **Method and Materials:** A Monte Carlo model of a cylindrical diode (from Rikner and Grusell) has been constructed. The diode is put on the central axis of a cylindrical water phantom and the dose ratios of water/silicon at various depths in 6 MeV electron beams are calculated. The dose ratio is also calculated for a bare silicon pellet of the same size as the active volume of the diode. Both calculated dose ratios are compared with the calculated water/silicon restricted stopping-power ratio (SPR) as a function of depth. The dose ratio is calculated as well for various field sizes at the reference depth in the 6 MeV electron beam. **Results:** For the diode model, the dose ratio versus depth in electron beams is nearly flat: within 1% from near the phantom surface to R_{50} (calculation uncertainty <0.5%). For the pellet, the dose ratio versus depth behaves almost the same as the Spencer-Attix water/silicon SPR with Δ = 100 keV. It varies more than 3% with depth. The diode dose ratio changes by less than 0.5% for field sizes ranging from 2 to 10 cm (beam radius) although it is 1.6% smaller in a 1 cm radius beam. **Conclusion:** The silicon pellet behaves like an ideal Spencer-Attix cavity with Δ slightly greater than 100 keV. The Si behind the active region plays an important role in making the overall dosimeter response flat within about 1% per unit dose to water. The silicon diode is an excellent dosimeter for electron beams since its response relative to the dose to water changes little with respect to the depth in phantom or the field size of source.

TU-D-224C-07

Using Convolution Superposition to Guide Denoising of Monte-Carlo Dose Distributions

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Purpose: Monte Carlo (MC) dose calculations can be accurate but are time consuming as well. In contrast, convolution superposition (CS) offers a fast and smooth result but is potentially less accurate. In this work, we attempt to take advantage of the convolution superposition result and noise filtering methods to guide and accelerate Monte Carlo calculations. **Method and Materials:** We investigated two methods to utilize convolution-super position in Monte-Carlo denoising. In the first method, the residual difference between MC and the overall result is denoised using multi-scale (wavelet and contourlet) methods and iteratively added to the overall result. The iterations are initialized by the CS result. In the second method, low-frequency components are determined using Mont Carlo calculations whereas high frequency components are determined using CS results. 3-D Butterworth filters are used to make the split. The methods were evaluated using a lung and head and neck case. The MC dose distributions were calculated by the open-domain Dose Planning Method MC code with varying number of histories (125000, 250000, and 500000) and corresponding uncertainties of 6%, 4%, and 3%, respectively. **Results:** We observed that both the residual-based contourlet method and frequency splitting by Butterworth filters provided better performance than using wavelet-based residuals. Frequency splitting is much faster (a few seconds) compared to contourlet computations (10-15 min in the current prototype implementation). **Conclusion:** This is the first demonstration of the (hybrid) use of fast dose computations to guide and accelerate Monte Carlo calculations. We demonstrated two promising techniques. Of the two, the contourlet method retains more of the high-frequency results from the Monte Carlo simulations, whereas the Butterworth frequency-splitting method is much faster. The results are promising for future investigations.

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TU-D-224C-08

Effect of Different Physical Processes and Data Sets On HVL Calculations

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Purpose: To study the role of electron impact ionization (EII), Rayleigh scattering, and photo-absorption and bremsstrahlung cross-section selection in Monte Carlo half value layer (HVL) calculations. **Method and Materials:** The NRC x-ray system is modeled using BEAMnrc to obtain phase space files for several x-ray beam qualities (between 135 kV and 200 kV). An EGSnrcMP user-code, cavity, is used to compute air-kerma ratios (with and without absorber) at 1 m from the source on a 5 mm radius scoring field. This user-code allows one to include several geometries in one run, which further reduces the uncertainty in the kerma ratios due to the strong correlations. These ratios are then used to obtain the HVL's from a quadratic fit of the simulated data. **Results:** Excluding Rayleigh scattering produces a 6 % overestimation for all beam qualities. The effect of neglecting EII is energy dependent and overestimates the HVL by 1.5% at 135 kV and by 5% at 200 kV. Using Bethe-Heitler bremsstrahlung cross sections instead of the NIST cross sections causes an underestimation between 3% at 135 kV and 6% at 200 kV. Selecting the photo-absorption cross sections from the Storm and Israel tabulations instead of XCOM overestimates HVL's by 0.4%. EGSnrc reproduces the measured HVL's within 2% or better when the best cross-sections available are employed. **Conclusion:** EII and Rayleigh scattering have a significant impact and must be included in HVL calculations. HVL's in this energy range are not very sensitive to the selection of photo-absorption cross-sections. NIST bremsstrahlung cross sections should be used in order to achieve better agreement with the experiment. A 2% reduction of the photo-electric cross-sections or a slightly harder bremsstrahlung spectrum would remove the remaining discrepancies between calculated and measured HVL values. Such changes are within the reported uncertainties of these cross-sections.

TU-D-224C-09

On the Discrepancies Between Monte Carlo Dose Calculations and Measurements for Varian Megavoltage Photon Beams

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Significant discrepancies between Monte Carlo dose calculations and measurements for the Varian 18 MV photon beam with a large field size (40×40 cm^2) were reported by different investigators. The GEPTS Monte Carlo code is used to investigate these discrepancies and a new geometry model (New Model) of the Varian 2100EX linac is implemented. A misrepresentation of some geometric parameters in previous investigations (Old Model) was suggested by Chibani in his AAPM presentation (2004) and later confirmed by the manufacturer. The entrance and exit radii of the primary collimator are 2-mm larger than previously thought. The primary collimator is also found to be 2-mm shorter and 1-mm closer to the target. The New Model also includes the lead shield between the monitor chamber and the Y jaws. A detailed analysis of the phase space data (before and after the primary collimator, after the flattening filter, and at the phantom surface) shows the effect of the changes introduced in the New Model on the beam characteristics (photons and electrons). The main source of the dose discrepancies between measurements and calculations based on the Old Model is the underestimated electron contamination. The photon and electron fluences at isocenter are 4.7% and 30% larger in the New Model in comparison with the Old Model. The flattening filter and lead shield contribute 50% and 10.1% of the total electron contamination at isocenter, respectively. Dose calculations based on the GEPTS implementation of the New Model for the 18 MV open and filtered (2-mm Pb foil) fields are in excellent agreement with measurements. Local differences are less than 1.5% for depths larger than 1 cm. Monte Carlo simulation of the ionization chamber response shows that difference between calculated and measured percent depth ionizations can be reduced to less than 3% even on the surface.

Therapy Scientific Session — Valencia A

IMRT Optimization and Delivery

TU-D-ValA-01

Role of Collimator Angle Optimization in Intensity Modulated Radiation Therapy

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Purpose: IMRT optimization involves several treatment parameters producing a complex, unstable and computationally challenging problem during its search of an optimal plan in a reasonable time. Most parameters have been studied in IMRT optimization except the collimator angle, which is investigated in this study. **Method and Materials:** Five head-and-neck and five prostate cases are selected. The head -and-neck and prostate PTVs range between 79.6-441 cm^3 and 86.2-250 cm^3 respectively, whereas the OAR volumes vary from 11.0-46.3 cm^3 and 41.1-312 cm^3 respectively. The patients are treated with five or seven fields equally distributed, 0-degree collimator angle, using the 1 cm leaf MLC from a Siemens Primus accelerator based on the plan generated using the Nucletron Oncentra treatment planning system. While dose-volume constraints are kept the same as in the patient's initial treatment plan, collimator angles are varied systematically (0-90 degrees) and a new treatment plan is optimized for each collimator angle. The number of beamlets, monitor units (MU) and DVHs for each collimator angle are compared. **Results:** The variation of the total number of beamlets with collimator angle follows the shape of a parabola and peaks at 45^o collimator angle for all patients. However, the MUs appear to be relatively independent of the collimator angle. The PTV dose coverage statistics for each patient are relatively independent of the collimator angle. Similar observations are noted for all the OARs, except for the small structures for which differences could be observed in the DVHs between the different collimator angles. **Conclusions:** Collimator angle does not play a significant role in IMRT optimization, as long as the PTV overage is adequate. This provides an additional freedom to choose from 0- 90 degree of the collimator angle for long fields without compromising the coverage with limited MLC range or treatment time.

TU-D-ValA-02

Relationship of EDU-Based and Dose-Based Plan Optimization

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Purpose: The essence of inverse planning is how to rank objectively the competitive treatment plans**.** The purpose of this work is to show the equivalence of recently introduced EUD-based and the conventional dose-based objective function and to setup a unified framework in the dose domain for IMRT inverse planning. **Methods:** The dose-based objective function such as the quadratic function treats each voxel within a structure equally, whereas the EUD-based objective function aims to take into account of dose-volume effect when ranking the candidate plans**.** For the conventional approach to accomplish what an EUD method does, we partially "break" the implicit constraint that a structure is a mathematically uniform entity with all voxels having the same identity and assign each voxel a voxel-specific ranking (or penalty scheme)**.** Algorithmically, this is accomplished by assigning a voxel-specific importance or a voxel specific prescription dose**.** The seemingly insolvable task of determining a large number of voxel-specific importance/prescription is dealt by heuristically relating them to the actual local doses**.** We show that this strategy is a more general ranking scheme, which can not only model the volumetric behavior but also the higher order factors beyond the dose-volume effect**.** EUD and other dose-volume formalisms represent special cases of the general framework**. Results:** A unified inverse planning framework is established for inverse planning**.** By assigning higher importance to the voxels within the target volume but close to the margin with a critical structure, while simultaneously assigning higher importance to the voxels within the critical structure close to the target volume, the dose to the target volume is dramatically improved in comparison with the conventional approaches**. Conclusions:** The EUD-based approach can be reformulated into the realm of conventional dose-based formalism without using biological parameters**.** The formalism allows us to design IMRT plans that would otherwise be unattainable**.**

TU-D-ValA-03

Continuous Intensity Map Optimization (CIMO): A Novel Leaf-Sequencing Algorithm

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Purpose: In IMRT planning, leaf-sequencing algorithms are used to translate optimized intensity maps into deliverable aperture shapes**.** We have developed a novel approach to leaf sequencing called continuous intensity map optimization (CIMO)**.** The CIMO algorithm can significantly reduce the number of segments required for IMRT delivery**.** A unique feature of the CIMO algorithm is that it operates directly on continuous intensity maps**.** Consequently, the intensity maps do not need to be divided into discrete levels**. Method and Materials:**
CIMO uses a simulated annealing algorithm to optimize the aperture shapes and weights with a goal of minimizing the discrepancies between the optimized and sequenced fluence maps**.** We have benchmarked the performance of the CIMO sequencer against the algorithms in the Pinnacle[3] and Eclipse treatment planning systems**. Results:** When the CIMO sequencer was applied to 10 IMRT plans from the Pinnacle[3] planning system, the average number of segments was reduced from 133 to 62 (a 54% reduction)**.** The average number of monitor units was reduced from 646 to 555 (a 14% reduction)**.** The CIMO algorithm also provided a 36% reduction in the average root mean square errors between the optimal and sequenced fluence maps**.** Additionally, the CIMO sequenced plans provided more uniform PTV coverage with comparable sparing of critical structures**.** The average standard deviation of the PTV dose distribution decreased from 9.6 to 7.4 cGy**.** When the CIMO algorithm was applied to 5 IMRT patients from the Eclipse planning system, the average number of segments was reduced by 46% and the average number of monitor units was cut by 31%**.** Equivalent plan quality was observed**. Conclusion:** As compared with both commercial systems, the CIMO algorithm resulted in equivalent or improved plan quality while providing a significant reduction in the required number of segments and monitor units.

TU-D-ValA-04

Adaptive Diffusion Smoothing: A Novel Method to Control IMRT Field Complexity Based On the Diffusion Equation

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Purpose: To introduce and evaluate adaptive diffusion smoothing (ADS), a novel procedure designed to preferentially reduce IMRT beam complexity based on any case related parameter inside the optimization. **Method and Materials:** The diffusion equation was used to develop a procedure in which IMRT beams are smoothed using coefficients defined for each beamlet**.** The coefficients can be a function of any parameter and dictate the degree of smoothing allowed for each beamlet**.** The ADS procedure was incorporated into our optimization system as a weighted objective function penalty and several possible ADS coefficient definitions were investigated**.** Coefficients were designed to promote 1) uniform smoothing everywhere, 2) smoothing based on beamlet intensities, and 3) smoothing based on beamlet gradients with respect to the plan objectives**.** The method has been validated on a phantom and studied in clinical sites including prostate**. Results:** The addition of the ADS penalty in the objective function, for all three coefficient types, produced plans with reduced modulation and minimal dosimetric impact in the phantom**.** Each ADS coefficient definition had merit, but gradient-based coefficients showed the most potential for reducing beam modulation without affecting dosimetric plan quality**.** For example, in a prostate plan, this method reduced MU 40% while preserving full target coverage and increasing mean normal tissue doses by less than 2.2 Gy. **Conclusion:** A unique method based on the diffusion equation and used within the objective function has been developed to control IMRT beam complexity**.** This method, called adaptive diffusion smoothing, has been applied to phantom and clinical cases, and was able to reduce modulation significantly while preserving dosimetric plan quality**.** Adaptive diffusion smoothing is a promising tool for ensuring that only the necessary amount of beam modulation is used, promoting more efficient and accurate IMRT planning, QA, and delivery.

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TU-D-ValA-05

Self-Correction of DMLC Delivery Errors Based On Feedback From On Flight Intensity Calculations

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Purpose: To deliver DMLC intensity modulated therapy accurately in the presence of errors related to unaccounted target motion, improperly executed motions of leaves and imprecise control of beam intensity rate during delivery. **Method and Materials:** The intensity delivered to each target point is calculated on-the-fly under the assumption of unidirectional leaf motion in the target frame of reference**.** The delivered intensity is then compared to the intended intensity**.** If a discrepancy arises, the leading leaf's trajectory is left unchanged and the following leaf's trajectory is modified to correct the error**.** Using the derived formulas, the following leaf is sped up or slowed down so that it efficiently corrects the error without unnecessarily compromising the delivered intensity to other points of the target**.** The formulas only consider the discrepancy between the delivered and intended intensity**.** They are not directly dependent on the actual and intended leaf positions as a function of time**.** This means that the leaves will not, in general, return to their originally planned trajectories**.** After correction is complete however, the correct intensity will be delivered to the rest of the target**. Results:** Two representative examples of self-correction are shown**.** The first uses a static target, and shows how an intensity error due to an unintended leaf velocity can be corrected**.** The second shows a similar error, but instead uses a rigid moving target**. Conclusions:** An algorithm is developed to modify the following leaf trajectory when a discrepancy between the delivered and intended intensity arises**.** The results show that it is feasible to correct some errors in DMLC delivery without interrupting delivery**.** The tolerance for errors can therefore be set much higher than current control algorithms**.** This should lead to considerably decreased number of beam interruptions at delivery.

TU-D-ValA-06

Incorporation of Modulation Range Constraints Into a Gradient Search Algorithm for IMRT Optimization

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Purpose: Hardware-sensitive optimization for IMRT results in more conformal dose distributions; however, most planning systems neglect hardware constraints, most likely due to the complexity of incorporating them into gradient search algorithms. An important limitation of delivery systems is the modulation range, which we demonstrate can be incorporated as a hard constraint into gradient search algorithms. **Method and Materials:** We used a commercial treatment planning system (TPS) for calculation of dose-deposition coefficients, which were exported to optimization software that we developed. For a beam j comprised of beamlets i, we reformulated the optimization problem such that the fluence of beamlet i, ϕ_i, is the product of the weight of beam j and the transmission of beamlet i, $\phi_i = w_j t_i$. A gradient search algorithm determined the optimal values of w_j and t_i subject to the constraints $w_j \geq 0$ and $T_{minimum} \leq t_i \leq 1$. The resulting fluence distributions were exported back to the TPS for MLC leaf sequencing and dose calculation. We applied the method to a phantom simulating head and neck re-irradiation, a situation that requires very low fluence values to protect the spinal cord. Using the same cost function parameters, we varied the minimum transmission constraint. After optimization, leaf sequences for dynamic MLC delivery were determined and the dose calculated. All plans were normalized such that 95% of the target received the prescription dose. **Results:** Target mean and maximum doses were essentially identical for all transmission constraint values. The maximum spinal cord dose was 33% of the prescription dose for no transmission constraint. The minimum value, 30.8%, occurred for an 8% transmission constraint. **Conclusion:** Modulation constraint is a good approximation of hardware transmission limits and could be readily incorporated into existing TPSs. Furthermore, initial results suggest that transmission constraint beyond the intrinsic hardware limitation may be beneficial.

TU-D-ValA-07

Prioritized Prescription-Goal Treatment Planning for IMRT: The Effect of Constraint Moderation

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Purpose: Determining the 'best' optimization parameters in IMRT planning is typically a time-consuming trial-and-error process with no unambiguous termination point. Recently we and others proposed using a goal-programming approach which better captures the prioritization of clinical goals without introducing ambiguous user-input parameters. We consider here the effect of adding 'slip' to this method, which allows for slight degradations in metric performance compared to maximum achievable. **Method and Materials:** In the first phase of the optimization process, only the highest-order goals are considered (target coverage and dose-limiting normal structures). In subsequent phases (levels), the achievements of the previous step are turned into hard constraints and lower-order goals are optimized subject to these constraints. Slip factors were introduced to allow for slight violations of the constraints. Linear as well as quadratic goal terms were evaluated for performance as well as dosimetric 'steerability.' The resulting constraints can also be expressed as linear or quadratic equations. **Results:** Focusing on head and neck cases, we present several examples of treatment plans using prioritized optimization. These are compared to conventional IMRT plans in terms of dosimetric properties and optimization speed. The main advantages of the new optimization method are (1) its ability to generate plans that meet the clinical goals/prescriptions without tuning any weighting factors or dose-volume constraints, and (2) the ability to conveniently include more terms which represent elements such as beam weight smoothness. Lower level goals can be optimized to the achievable limit without compromising higher order goals. Modest slip factors improved overall performance. **Conclusion:** The prioritized prescription-goal planning method including slip factors allows for a more intuitive and human-time-efficient way of dealing with conflicting goals compared to the conventional trial-and-error method of varying weighting factors.

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TU-D-ValA-08

Geometric Considerations for Optimizing Beam Directions for IMAT Treatment of Lung Cancer with Mediastinum Nodal Irradiation

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Purpose: Based on geometric considerations, we optimized beam directions and arc ranges for intensity-modulated arc therapy (IMAT) to maximize the sparing of lung and spinal cord while treating the mediastinum nodes and gross disease. **Methods and Materials:** A phantom with multiple planning target volumes (PTV) and lung with varying geometric shapes was created on Pinnacle 7.6c (Philips Medical Systems). A spinal cord was placed posteriorly. Mean lung and maximum cord dose were obtained for the various geometries for AP/PA and IMAT fields that were designed to spare the cord. We combined AP/PA and IMAT fields in order to achieve an optimal plan for each geometry, and seek correlations between patient geometry and their optimal relative weights. This combination of AP/PA and the IMAT fields were used to treat a patient in 2004 diagnosed with non-small cell lung cancer with concurrent chemotherapy. **Results:** For a circular PTV in the phantom, the mean lung dose varied for AP/PA between 50% and 29% of the mean PTV dose, depending on the lung geometry, and for IMAT, between 50% and 46%. The maximum cord dose was 107% for AP/PA versus 33% for IMAT. Optimized composite plan of AP/PA and IMAT were created for each phantom geometry, balancing PTV dose, lung and cord tolerance. For the patient plan, the prescription dose was 60Gy, and the composite AP/PA-IMAT plan gave a maximum cord dose of 45Gy with mean lung dose =16.1Gy and V_{20Gy} =23%. Patient completed treatment and had no acute or late lung or spinal cord toxicities. **Conclusions:** IMAT was found to be useful in sparing the cord but not the lung, while AP/PA maximizes lung sparing but not the cord. A combination of AP/PA and IMAT provides an optimal class solution for treatment of lung cancer where mediastinum nodal irradiation is indicated.

TU-D-ValA-09

Optimized Removal of the Tongue-And-Groove Underdose Via Constrained Partial Synchronization and Variable Depth Recursion

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Purpose: IMRT leaf sequencers that remove tongue-and-groove underdosages (TGU) significantly increase the number of segments by using full synchronization (FS). This work aims to minimize the increase in the number of segments by using Constrained Partial Synchronization (CPS) and Variable Depth Recursion (VDR). **Method and Materials:** Adjacent leaves simultaneously expose cells in an intensity map to deliver Vs, determined by cell values V0 and V1 (V0 <= V1). The tongue-and-groove ratio, TGR, is (V1-Vs)/(V0-Vs). In FS, TGR = infinity, while for CPS it is constrained to be greater than the minimum required to remove TGUs. The TGU for various TGRs were measured with film to determine this minimum TGR. The extraction and sweep leaf sequencing processes used in VDR optimization were modified to use CPS. The algorithm was tested on 1400 random maps (3 to 16 levels) and 42 clinical maps. **Results:** For a Siemens MLC, the TGUs are 18%, 4%, and 0, for TGRs of 1, 1.5, and 2, respectively. For the clinical cases, the average increase in the number of segments relative to VDR with no synchronization was 7% for TGR=1.5, and 32% for VDR with FS. A fully synchronized sweeping window produces 170% more segments. For the random maps, an unsynchronized sweeping window produced 1.5 to 2.5 times as many segments as VDR with CPS. Similar results can be obtained for interdigitating MLCs. This has implications for direct aperture optimization (DAO) algorithms that use the sweeping window as a starting point (Pinnacle), for which TGU has been observed. The concept of CPS can be applied to DAO algorithms, by choosing appropriate levels for each segment.**Conclusion:**
CPS combined with VDR removes the tongue-and-groove underdose while minimizing the number of segments.

Therapy Symposium Room 224 A
Symposium in Memoriam of C.J. Karzmark: Novel Treatment Modalities

TU-D-224A-02
Intro: Particles and Intensity Modulation
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In the past 15-20 years substantial research and development effort has been put into the optimization of photon beam radiation therapy, primarily into the development of intensity-modulation techniques (IMRT). As far as the development of photon IMRT delivery technology is concerned, we may have almost reached a point of diminishing returns. In recent years novel treatment modalities (other than photons) are gaining more attention, which goes hand in hand with the construction of a number of new proton therapy facilities in this country.

The physical advantage of proton therapy is indisputable, even though it is not always used to its full extent in clinical treatments: The blessing of the finite range of protons goes along with some uncertainty in the position of the steep distal dose gradient region in the patient. This is because the position of the distal gradient is affected by setup errors, internal organ motion, metallic implants, and biological effects, among others. Due to these reasons, the distal gradient is not currently used for dose shaping. The full clinical utilization of the physical advantage of proton therapy also requires beam scanning and intensity-modulated particle therapy (IMPT), which is in clinical use at only two centers.

The clinical benefit of proton therapy has been demonstrated for a relatively limited number of cases, and will be further studied as more proton centers are being brought on line. Of course, the benefit comes at a price. Several investigators now look into novel and potentially cheaper proton acceleration techniques, including laser acceleration, which will be discussed by Dr. Ma, and dielectric wall acceleration.

Outside of the USA the treatment with heavier charged particles, such as carbon ions, has become a topic of great interest, which will be reviewed by Dr. Jäkel. Both the treatment with protons and carbon ions open new avenues for image-guided radiation therapy: Those particle beams activate positron emitters in the patient, which can be visualized with PET scanners and serve as an in-vivo dosimeter, as explained by Dr. Parodi.

Last but not least, there has been renewed interest in lighter charged particles, namely electrons. The talks by Drs. Li and Papiez will show that electrons are a particularly attractive treatment option in combination with IMRT.

Educational Objectives:
1. To give a brief update of the state of the art of proton radiation therapy
2. To link the various presentations of this symposium

TU-D-224A-03
Will Protons Become Cheaper Some Day
C Ma*, Fox Chase Cancer Center, Philadelphia, PA

Given the physical advantages of protons and light ions in target dose conformity and normal tissue sparing over commonly used photon and electron beams, why is proton or ion beam therapy only offered at a few facilities worldwide? The answer is high cost. Conventional proton or ion facilities are either cyclotron- or synchrotron-based. The cost of the accelerator, treatment gantries and the building increases the total capital cost to about $100million for a proton facility and it can cost 2-3 times more for an ion facility. In this presentation we will look at alternative solutions that may provide more cost-effective proton and light ion beams for radiation therapy. We will review recent developments in compact accelerator designs using superconductors and advances in particle acceleration using laser-induced plasmas. Take laser-proton acceleration as an example, theoretical studies show that at a laser intensity of 10^{21}-10^{22} Wcm^{-2} protons may be accelerated up to 300MeV with a spectrum and angular distribution. Experimental facilities dedicated to laser-proton acceleration for cancer treatment have recently been established in the US, Japan and France. Because of the small acceleration distance a laser-proton/ion accelerator is expected to be much more compact than conventional cyclotrons or synchrotrons and once developed may be the best candidate accelerator for particle therapy.

Educational Objectives:
1. Review existing accelerator designs and alternative compact accelerator designs
2. Review recent advances in laser technology and laser-ion acceleration
3. Discuss potential applications of laser-accelerated protons for radiation therapy

TU-D-224A-04
How Much Better Are Carbon Beams
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Deutsches Krebsforschungszentrum , 69120 Heidelberg , Germany

In 2004 hadron therapy celebrated its 50th anniversary and between 1954 and 2004 nearly 40'000 patients were treated with protons and about 4500 with heavier particles (mainly helium, carbon and neon). Especially within the last decade, hadron therapy has gained increasing interest. In mid 2004, 22 proton facilities were operational and about half of all patients treated with protons received their treatment within the last 5 years. There are currently 3 facilities treating patients with carbon ions, two of them in Japan within a clinical setting. In Germany, a research therapy facility is in operation at the German heavy ion research Laboratory GSI (Darmstadt) since 1997. Currently, the construction of a new hospital based facility at the Heidelberg University hospital is ongoing and the facility is scheduled to start clinical operation in late 2007. Furthermore, an Italian facility is under construction and Austrian and French projects have been approved recently.
The Heidelberg facility will be the first one worldwide that will be equipped with an isocentric scanning gantry. The facility will offer proton and carbon ions beams and thus will enable a direct comparison of treatment outcome applying both modalities using the same beam delivery system. The Heidelberg facility is designed to produce also beams of other ions like Helium or Oxygen and thus offers a large research potential to investigate which ion is best suited for which application.
An outline of the current potential of ion radiotherapy will be given and some open questions will be addressed. This includes a description of passive and active beam shaping systems, as well as their implications for treatment planning and dosimetry. The potential of ions will be compared against IMRT and radiotherapy with proton beams on the basis of their physical and radiobiological properties. A short comparison of patient treatment plans for the various modalities will also be presented. The current clinical results gained with ions in Japan and Germany will be reviewed and an outlook on the clinical program in Heidelberg will be given.

TU-D-224A-05
Dose-Guided Particle Therapy with PET Imaging
K Parodi*, H Paganetti, H Shih, S Michaud, T Bortfeld, Massachusetts General Hospital, Boston, MA

Positron emission tomography (PET) is increasingly considered a promising technique for in-vivo, non invasive verification of the actual treatment delivery in ion therapy. Positron-emitting isotopes such as ^{11}C (half-life $T_{1/2}$=20.4 min) and ^{15}O ($T_{1/2}$=2 min) are produced in tissue along the ion beam penetration as a by-product of irradiation and can be potentially visualised by PET as a spatial marker of radiation dose deposition. PET image guidance can contribute to a better clinical exploitation of the physical advantages of ion beams. It may improve confidence in the planning and delivery of more conformal treatments or allow for adaptive strategies in case of detected disagreements between the intended and actually delivered fields during fractionated radiotherapy.

As opposed to heavier ions like carbon, the positron activation induced by proton beams is limited to target (no projectile) fragments of the irradiated tissue. This results in a weak spatial correlation between PET images and dose. Nevertheless, previous phantom studies of several groups indicated feasibility and usefulness of the method for proton therapy. Information on the dose delivery and the beam range in the patient can be gained by comparing the measured activity with a model prediction, as already

clinically implemented for therapy with stable carbon ion beams elsewhere in Germany.

Issues related to the possible on-line (i.e. during treatment) or off-line (i.e. after treatment) imaging strategies will be briefly addressed. The presentation will focus on the first clinical pilot study recently concluded at Massachusetts General Hospital, Boston. Nine patients with a variety of tumour types and anatomical sites were imaged at a commercial, LSO-based PET/CT scanner for 30 min starting within 20 min after single or multi-field proton irradiation. Measured PET/CT images are compared to predictions based on Monte Carlo techniques combined with functional information taken from the literature and from the measured activity decay curves. The same Monte Carlo methods were also used to calculate the pattern of dose deposition for an additional direct comparison with the treatment plan, to enforce the clinical value of the comparison between measured and calculated PET images. First conclusions on clinical feasibility, potential and limitations of off-line PET/CT imaging of proton therapy will be discussed.

This lecture will provide an overview on the physical principles and issues of the unconventional application of PET to treatment verification in ion therapy, with a more detailed insight on the role of PET/CT image guidance after proton treatment.

Educational Objectives:
1. Understand the physical principles of positron activation induced by therapeutic ion irradiation
2. Understand the issues related to ion treatment verification by means of PET imaging, including the strategies for data acquisition and analysis
3. Understand the issues related to clinical application of PET/CT imaging after proton therapy

TU-D-224A-06

Advanced Mixed Beam Therapy Using MERT and IMRT

J S Li*, C-M Ma, Fox Chase Cancer Center, Philadelphia, PA

Purpose: To review and highlight the current status of the investigation and implementation of advanced mixed beam radiation therapy (MBRT) using energy- and intensity-modulated electron radiotherapy (MERT) and intensity-modulated photon radiotherapy (IMRT). **Methods and Material:** Disease sites such as post-mastectomy chest wall, breast and head and neck etc. are better suited for MERT or MBRT. Feasibility studies on this topic have been performed. Monte Carlo dose calculations, optimization methods and beam delivery systems using prototype electron MLCs or existing photon MLCs have been investigated. Smaller SSDs (60–70cm) are recommended when existing photon MLCs are used for beam delivery on Simens or Varian accelerators. Surface dose and beam properties are studied using the Monte Carlo method and compared with measurements. Treatment plans for head and neck and breast are generated with advanced MBRT using IMRT and MERT. MBRT beam delivery accuracy and efficiency are evaluated with phantom measurements. **Results:** Results show that the Monte Carlo method can provide accurate (2% or 2mm) dose distributions for MBRT. MBRT plans show advantageous dose distributions because IMRT provides superior lateral dose conformity while MERT added extra conformity in the depth direction. The combination of IMRT and MERT provides excellent dose conformity for treatments involving shallow target volumes such as breast and head and neck. Our results of MBRT for 78 breast patients showed that the acute skin complications were significantly reduced in a hypofractionated breast trial. **Conclusion:** MBRT can provide much improved target dose conformity and uniformity, adequate skin coverage/avoidance and significant reduction in the dose to the adjacent normal organs and critical structures for shallow tumor treatment. Preliminary results have shown great potential of this technique for treating breast, chest wall and head and neck cancers.

TU-D-224A-07

Image-Guided IMRT and Very High Energy Electrons (VHEE)

L Papiez*, Indiana University, Indianapolis, IN

Purpose: To evaluate the feasibility of very high-energy electron beams (VHEE, 150 - 300 MeV) for radiotherapy. The specific goal is to exploit fast scanning capabilities of pencil VHEE beams for better targeting of moving tumor tissue and moving sensitive organs in 4D image guided intensity modulated radiation therapy (IGIMRT). **Method and Materials:** VHEE have dosimetric characteristics comparable, and for some applications superior, to photon beams. The dosimetry of the VHEE treatments can be verified by means of Monte Carlo simulations. The dosimetry of the VHEE treatments for moving tissues requires the knowledge of body geometries in subsequent phases of cyclical motions of regions of patient body that undergo treatment. The mutual interaction of doses delivered at different phases allows for optimal treatment in 4D radiation therapy. Therefore, optimization of 4D radiation therapy involves calculating jointly the set of all intensities at all phases of the cyclical tissue motion. This in turn means that optimal 4D IGIMRT plans require delivery of intensity maps that appropriately distribute given fractions of intensity maps over particular phases of moving tissues. Existing delivery systems for IMRT therapy (step and shoot IMRT and/or DMLC IMRT) are not capable of efficient delivery of predetermined by 4D IGIMRT planning "intensity map rates". In contrast, fast scanning beam of VHEE electrons provides ideal tool for 4D IGIMRT delivery. **Results:** A sequence of dose calculations for representative VHEE beams are presented and compared with traditional photon beam irradiations. Examples illustrating VHEE intensity rate maps for delivery of optimal 4D IGIMRT are presented and their delivery discussed in the context of MLC and electromagnetic pencil beam scanning capabilities of radiation devices. **Conclusion:** VHEE devices, capable to provide fast, electromagnetic scanning of pencil beams, are capable to efficiently deliver "intensity rate maps" of truly optimized 4D IGIMRT treatments.

Workshop — Room 230 C

Digital Radiography QC Workshop: Part I - Vendor Presentations

TU-D-230C-01

Digital Radiography QC Workshop I and II

L Goldman*, Hartford Hospital, Hartford, CT

Computed radiography and digital radiography systems now comprise a large segment of radiography work. It is important that appropriate performance testing and quality control (QC) tools and procedures be made available for these systems. The vendors and/or manufacturers of digital imaging systems may provide–or make available–test tools, software and procedures for performance evaluation and routine quality control testing of their digital systems. Currently, such tools and programs vary significantly from manufacturer to manufacturer.
This two-part workshop will include both formal presentations and hands-on demonstrations. During the first half of the workshop, each participating vendor or manufacturer will present a brief (12-15 minute) overview of tools and procedures for performance testing and QC of their systems. The second half of the workshop is dedicated to hands-on demonstrations at table-top exhibits hosted by each participating vendor. Exhibits will include test tools, workstations and samples of performance testing and QC test procedures.
Companies participating in this workshop will include Agfa, Fuji, General Electric, Kodak, Konica, IDC, LoDox, Philips and potentially others.

Learning Objectives:
1. To understand performance test procedures used by various DR/CR systems
2. To see types QC test tools and procedures made available with DR/CR systems
3. To obtain hands-on demonstration of DR/CR ttesting and QC procedures

Exhibit Hall F

Therapy
Moderated Poster Session
Moderated Poster - Area 1 (Therapy): Brachytherapy I

TU-EE-A1-01

Capabilities of a CT-Suitable, Patient-Adaptive HDR/PDR Intracavitary Brachytherapy Applicator for the Treatment of Cervical Cancer

M Price*, K Gifford, J Horton, P Eifel, F Mourtada, University of Texas MD Anderson Cancer Center, Houston, TX

Purpose: To demonstrate the capability of a prototype, high-dose-rate/pulsed-dose-rate (HDR/PDR) intracavitary brachytherapy cervical applicator to be (a) imaged using computed tomography (CT) with minimal artifacts as compared to current, clinically-utilized applicators and (b) deliver dose to a simulated disease plane that is at least equivalent to that delivered by the FW applicator while delivering less dose to multiple, simulated rectal planes for equivalent loadings. Capability (b) demonstrates the prototype applicator's ability to adapt to varying patient anatomies utilizing a remotely adjustable shield contained within the colpostat. **Method and Materials:** CT image sets were acquired of the Fletcher-Suite-Delclos (FSD), Fletcher-Williamson (FW), and prototype applicators (utilizing a step-and-shoot technique) and artifacts generated by each were compared qualitatively. Images were acquired of the applicators positioned parallel to the table and in positions that simulated applicator placement during treatment. Using film validated MCNPX Monte Carlo (MC) models of the prototype and FW applicators, dose comparisons (min, max, average, and dose-surface histograms) were made in simulated disease (1cm medial to colpostat) and multiple rectal (1cm distal and 0, 0.5, and 1cm medial to the colpostat) planes. **Results:** Preliminary results indicate that the prototype applicator is CT-friendly; qualitatively minimizing anatomy-obscuring artifacts compared to equivalent FW and FSD image sets. Additionally, the prototype applicator is able to deliver comparable dose levels (within +/- 5%) to a simulated disease plane while reducing dose (32% average) to varying simulated rectal planes when compared to equivalent FW treatments. **Conclusion:** The prototype applicator is able to be CT imaged with minimal artifacts and substantially reduce dose delivered to the rectum while maintaining dose delivered to disease when compared to current ICBT technologies. Currently, the model is being extended to include two prototype applicators and a 15^{o} tandem so that dose-volume histograms can be generated using specific-patient cases of varying anatomical geometries.

TU-EE-A1-02

Quality Assurance of Partial Breast Irradiation Using Permanent Breast 103Pd Seed Implant (PBSI)

JP Pignol*, R Sankreacha, B Keller, E Rakovitch, G Czarnota, Sunnybrook and Women's College Health Science Centre, Toronto, Ontario, CA

Purpose - For early stage breast cancer, accelerated partial breast irradiation using High Dose Rate brachytherapy appears as effective as whole breast radiation. A permanent breast seed implant (PBSI) technique has been developed that realizes the implantation of ^{103}Pd seeds under ultra-sound guidance in a single one-hour session. The objective of this study is to compare early and delayed post-implant dose distribution to assess the Quality of the procedure. **Material and Methods** - A Phase I/II clinical trial has been activated in May 2004 and as of February 2006 fourty seven patients have received PBSI. A minimal peripheral dose of 90Gy was prescribed to a volume corresponding to the CTV plus a margin of 1.5 cm. Each patient has a CT scan immediately following seed implantation and another one at two months. After identification of the seeds, new plans were calculated using the MMS TPS. **Results:** - On average, 70 seeds are used per patient, with an activity ranging from 1.59U to 2.7U per seed. The V_{100} values demonstrate a satisfactory coverage and minimal variations over the course of 2 months. V_{100} were improving over time demonstrating a learning curve. The V_{200} for both the PTV and CTV shows significant and dramatic increases over time (65% and 87% respectively, $p<0.001$). The mean PTV and CTV volumes were small and do not vary significantly between the "immediate" and two month post-implant. **Conclusions** - Post-implant PBSI Quality Assurance data shows adequate dose coverage of the target volumes that remains stable over time suggesting that there is no significant seed motion. Significant changes in the hot-dose sleeves are seen two months from seed implantation. This could be due to a breast oedema at the time of implant that disappears with time and/or to the development of a retractile fibrosis over time.

TU-EE-A1-03

Determining the Air-Kerma Strength of 1cm Coiled Brachytherapy Sources

A Paxton*, L DeWerd, W Culberson, University of Wisconsin, Madison, WI

Purpose: To show the ability of a large-volume free-air chamber to experimentally determine the air-kerma strength of a new 1cm ^{103}Pd coiled brachytherapy sources and show its potential for determining the air-kerma strength of longer (2-6cm) coiled sources. **Method and Materials:** A Variable Aperture Free-Air Chamber (VAFAC) has been constructed for making air-kerma rate measurements of low-energy photon-emitting brachytherapy sources with photon energies up to 70 keV. The VAFAC has been used to determine the air-kerma strength of 1cm coiled brachytherapy sources. The present US air-kerma strength standard for low dose rate (LDR) brachytherapy sources is the National Institute of Standards and Technology Wide-Angle Free-Air Chamber (NIST WAFAC). The results obtained with the VAFAC were compared to air-kerma strengths determined with an Accredited Dosimetry Calibration Laboratory (ADCL) well ionization chamber (traceable to the NIST WAFAC) and direct measurement in the NIST WAFAC. At present, the WAFAC is unable to measure the air-kerma rate of the coiled sources longer than 1cm due to its geometric limitations. The VAFAC does not have the same geometric limitations as the NIST WAFAC, which extends its capabilities to measure sources up to 6cm in length. **Results:** It has been shown that air-kerma strengths determined for three 1cm length coils with the VAFAC are within 1% agreement with both an ADCL well ionization chamber and NIST WAFAC values. **Conclusion:** This work shows that the VAFAC can accurately determine the air-kerma strength of 1cm ^{103}Pd coiled brachytherapy sources. It also shows the ability of the VAFAC to measure sources up to 6cm in length, a feat which was previously impossible due to the limitations of the NIST WAFAC.

Conflict of Interest: Research sponsored by RadioMed Corporation.

TU-EE-A1-04

Monte Carlo Modelling of the Xoft AXXENT X-Ray Source

R. E. P. Taylor*, G. Yegin, D. W. O. Rogers, Carleton University, Ottawa, Ontario,

Purpose: To use the EGSnrc Monte Carlo (MC) code for calculations of photon energy spectra and TG-43 dosimetry parameters for Xoft, Inc's miniature x-ray brachytherapy source. The importance of MC treatment planning for brachytherapy is also investigated. **Method and Materials:** Calculations of in-air photon energy spectra and the dose distribution around the source in water were performed. The radial dose function, anisotropy function, and the absolute dose rate were calculated and compared with measurements made by Rivard et al (submitted to Medical Physics). Calculations were done to investigate how parameters ignored by TG-43 affect dose delivered to the medium. The effects of realistic breast tissue and a finite irradiated volume were investigated. **Results:** Calculated in air photon spectra show excellent agreement with measurements in the energy range of ~10-50kV. TG-43 dosimetry parameters agree well with measurements but show a significant dependence on incident electron angles. Comparison of the dose in water to breast tissue show that calculations done in water may overestimate dose to breast tissue. The difference in dose to breast and water varies greatly with distance from the source and differences as large as 18% occur near the source. Calculations done in an infinite medium overestimate dose at the surface by 7% when compared with the case of a source placed 2cm from the surface of a phantom. **Conclusion:** MC calculations of in-air photon energy spectra and TG-43 dosimetry parameters have been performed and agree well with measurements. Calculations show that by ignoring the effects of realistic tissues and finite irradiated volumes, the TG-43 dosimetry protocol may significantly overestimate dose delivered to a patient. Using MC would improve treatment planning accuracy allowing for better correlation of treatment outcome to dose delivered.

TU-EE-A1-05

The Use of Directional Interstitial Sources to Reduce Skin Dose in Breast Brachytherapy

L Lin*, R Patel, B Thomadsen, D Henderson, University of Wisconsin, Madison, WI

Purpose: To investigate the feasibility of reducing the skin dose with temporary LDR multicatheter breast implants with the use of directional ^{125}I interstitial sources in comparison to conventional HDR interstitial breast brachytherapy. **Method and Materials:** The treatment plan for a patient treated with HDR interstitial brachytherapy with ^{192}Ir was compared to a directional ^{125}I treatment plan in the same dataset. Directional sources contain an internal radiation shield that greatly reduces the intensity of radiation in the shielded direction. They have a similar dose distribution to non-directional sources on the unshielded side. Several dosimetric parameters are compared including target volume coverage, dose homogeneity index, and the skin surface areas receiving 30%, 50% and 80% of the prescription dose (S30, S50 and S80, respectively). The HDR prescription dose was 34 Gy in 10 fractions. **Results:** Similar excellent target coverage was achieved by both directional LDR and HDR (99.2% and 97.5%, respectively). Moreover, for a 170-cc target volume, the dose homogeneity index was 0.82 for both LDR and HDR (V100 was 211.4 cc or 225.7 cc, and V150 was 39.1 cc or 40.4 cc, respectively). However, with directional LDR, the following reductions in skin dose may be achieved: S30 is reduced from 100.6 cm^2 to 62.6 cm^2, S50 from 50.6 cm^2 to 16.1 cm^2, and S80 at 2 cm^2 to null. The reduction in V50 for the whole breast is more than 100 cm^3 (386.1 cc vs. 489.2 cc). **Conclusion:** As compared to HDR, directional interstitial ^{125}I sources allow similar dose coverage to the subcutaneous target, while significantly lowering the skin dose due to a quicker fall-off beyond the target. Directional LDR sources can produce a similar dose homogeneity index, but the biological characteristics are more tolerable to the patient and can potentially reduce the risk of late skin and subcutaneous toxicity.

TU-EE-A1-06

Application of TG_43U1 Formalisms to Calculate Dose Distribution Around a 5 Cm Long RadioCoil Source

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Purpose: To evaluate application of TG-43U1 parameters for the determination of dose distribution around a 5cm long RadioCoilTM™ source. In addition TG-43U1 recommended linear interpolation technique for 2D anisotropy function ($F(r,\theta)$ has been evaluated for elongated sources. **Materials and Methods:** Dosimetric characteristics of 5cm long RadioCoil™ brachytherapy source have been determined following TG-43U1 recommendations using MCNP5 Monte Carlo code. In addition dose profiles along the longitudinal axis of the 5cm long source have been determined using MCNP5 simulation and theoretical technique. Monte Carlo calculated dose profiles were compared with theoretically values to evaluate accuracy of TG-43U1 recommended formalisms for elongated brachytherapy sources. **Results:** TG-43U1 recommended dosimetric characteristic were utilized to calculate dose distribution around an elongated brachytherapy source. Fifth order polynomial fit to the $F(r,\theta)$ was applied to extend $F(r,\theta)$ from 0^o to 90^o for the points falling on the source. Dose profiles at radial distances 0.5, 1.0, 1.5, and 2.0cm away from the central axis of the source has been determined using Monte Carlo simulation technique and TG-43U1 recommended formalisms. Results of theoretically calculated dose profile were compared with Monte Carlo simulation data. Application of TG-43U1 recommended minimal radial distances for 2D anisotropy function for dose calculation indicated that $F(r,\theta)$ for additional radial distances are required for good agreement between the two methodologies for calculating dose distribution. In addition, linear interpolation technique recommended by TG-43U1 has also been investigated to extract $F(r,\theta)$ for the points falling in between the TG-43U1 recommended radii. **Conclusion:** Results of these investigations indicate that TG-43U1 formalisms can be extended for elongated brachytherapy sources, if $F(r,\theta)$ is tabulated for radial distances of 0.5 to 5.0cm with 0.5cm increment $L/2 \pm 0.2$cm. Moreover, with the addition of recommended radial distances for 2D anisotropy functions, the linear interpolation technique more closely replicates Monte Carlo simulated data.

Exhibit Hall F

Therapy
Moderated Poster Session
Moderated Poster - Area 2 (Therapy): IMRT Planning and Delivery

TU-EE-A2-01

A Response Surface-Based Approach to Beam Orientation Optimization in IMRT

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Purpose: To include all noncoplanar beam directions in the beam orientation optimization (BOO) problem in intensity-modulated radiation therapy (IMRT) treatment planning, and to demonstrate that high-quality treatment plans can be obtained using fewer beams than are typically used in equi-spaced plans. **Method and Materials:** Because the data storage requirements for each beam restrict the number of beams that can be considered in BOO, the majority of previous BOO research has focused on considering just coplanar angles and/or a handful of pre-selected noncoplanar directions, which comprise only a small subset of all solutions. In contrast, our approach allows for the generation of beam data for promising directions thus avoiding the data storage restriction and significantly increasing the size of the solution space, possibly leading to improved treatment plans. We use a response surface (RS) method that allows us to generate the beam data on-the-fly only as necessary. We consider the problem of adding a single (noncoplanar) beam to a locally optimal 3-beam solution, thus yielding a 4-beam plan. Several varying implementations of the RS algorithm were tested on six head-and-neck cases using gantry and couch rotations, each on a 10° grid. **Results:** The 4-beam treatment plans obtained using the RS method were comparable to locally optimal 4-beam solutions, and were also comparable to the 5- and 7-beam equi-spaced plans typically used in head-and-neck treatment plans. **Conclusion:** For head-and-neck cases, quality plans with fewer beams than standard 5-7 beam treatment plans can be obtained if BOO is applied. While the inclusion of noncoplanar orientations in BOO is useful in terms of improving the FMO objective function, the resulting improvements in the treatment plan are not always clinically significant.

This work supported in part by NSF DMI-0457394 and the NSF Alliances for Graduation Education and the Professoriate and Graduate Research Fellowship programs.

TU-EE-A2-02

New Field Splitting Algorithms for Intensity-Modulated Radiation Therapy

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Purpose: To develop new algorithms/softwares that optimally split any intensity-modulated fields of large widths into multiple subfields under the MLC maximum leaf spread constraint such that the total beam-on time for delivering the resulting subfields is minimized. **Methods and Material:** Due to the maximum leaf spread (MLS) constraint of MLCs, intensity-modulated fields used in IMRT whose widths exceed a given threshold must be split into multiple subfields. This results in increased beam-on time of the treatment. We studied two versions of the field splitting problems: 1) Splitting a large field into non-overlapping subfields along paths that are orthogonal to the MLC leaf motion direction (this is a generalization of field splitting along straight lines); (2) splitting with overlapping, allowing adjacent subfields to overlap with each other. We developed two new field splitting algorithms (called FSMP and FSO) for these two problem versions, which mathematically guarantee to minimize the total beam-on time of the splitting. Our algorithms are based on graph algorithmic techniques in computer science and linear programming tools in operations research. **Results:** We implemented our new algorithms, and experimented with them on 58 large intensity-modulated fields for 11 clinical cases obtained from the Department of Radiation Oncology, University of Maryland Medical School. We conducted comparisons with CORVUS 5.0, and with a recent field splitting algorithm (denoted by FSSL), which splits along straight lines. For every tested field, the total beam-on times of the four methods, CORVUS 5.0, FSSL, FSMP, and FSO, are always in decreasing order. Comparing with CORVUS 5.0 and FSSL,

our new algorithms showed considerable improvements (on average, 21% and 12%, respectively) in the total beam-on time. **Conclusion:** We developed two new field splitting algorithms under the MLS constraint of MLCs to minimize the total beam-on time. Our algorithms improved the previous field splitting approaches considerably.

TU-EE-A2-03

A Novel Patch Field Design Using Optimized Grid Filter for Passively Scattered Proton Beams

Y Li*, X Zhang, L Dong, R Mohan, UT MD Anderson Cancer Center, Houston, TX, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: For tumors with complex shape, a "patching" strategy to match the distal edge of the spread-out Bragg peak (SOBP) of the patch field with the lateral penumbra of the through field at 50% dose level, is often used in passively scattered proton therapy. The differences in the dose gradients at distal edge and lateral penumbra could cause hot and cold dose at the junction. The purpose of this study is to design an effective technique to improve the dose distribution at the patch junction. **Method:** We found that the distal fall-off of the SOBP can be customized by a two-dimensional grid filter placed perpendicular to the beam direction. An adaptive algorithm has been developed to optimize the grid filter to best match the dose distribution at the junction by taking into account the tissue heterogeneities in the beam path. The optimized grid filter is superimposed onto a compensator designed using the conventional patching technique by the treatment planning system to create a new compensator. An L-shaped target for a head and neck case was used to compare the plan optimized using our algorithm with the plan designed using the conventional patch technique. **Results:** We demonstrated that the SOBP at the distal fall-off region can be tailored by a simple grid filter. For the head and neck case studied, hot spots near the patch junction were almost completely eliminated using our technique. This was confirmed by the calculated dose distributions and dose volume histogram of the target.**Conclusion:** The gradient of the distal edge of the SOBP of the patch field can be optimally modified to match the penumbra of the through field with optimized grid filters to minimize hot and cold spots at the junctions. In addition to improved dose distributions, this method can significantly reduce the trial-and-error effort.

TU-EE-A2-04

A Hybrid Dose Evaluation Method for Rapid Monte Carlo-Based IMRT Optimization

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Purpose: To develop and test a hybrid method for optimizing IMRT plans using Monte Carlo (MC) dose calculation algorithms which retains the accuracy of MC while reducing the MC dose computational requirements. **Method and Materials:** A hybrid dose calculation strategy in which initial optimization is performed with a fast pencil beam (PB) algorithm using deliverable-based IMRT optimization. Following convergence, doses are re-computed with the VMC++ MC algorithm to determine correction factors for further PB-based optimization. The correction/re-optimization procedure is repeated until convergence. The hybrid method was benchmarked with respect to MC-deliverable—based optimization for 5-prostate IMRT plans. Figures of merit included number of MC dose computations required, final plan quality score, and optimization dose-volume indices. **Results:** The hybrid method required a maximum of 3 MC dose calculations to converge to a result which provided equivalent dose coverage to the complete MC-based optimization plan. The complete MC-based optimization required between 6 and 9 MC dose computations to converge, depending on the specific patient. After 2 MC dose computations, the hybrid plan quality score was equal to or less than the MC-based score for 4 of the 5 plans, the remaining plan required 3 iterations to achieve a score equal to that for the MC-based optimization. Monitor units for the hybrid and complete MC-optimization were within 5%. **Conclusion:** Hybrid PB-MC-IMRT dose calculation method is practical and results in plans equivalent to those achieved when MC-dose calculation is used for all optimization iterations. The hybrid method reduced the number of MC calculations by a factor of ~3, reducing overall optimization time by a factor of 2.8, and allowing for VMC++ MC-based optimization to be completed in <30 min on a 20×2.4 Ghz CPU cluster. (Supported in part by NIH-R01CA98524).

TU-EE-A2-05

TomoDose: A Daily Quality Assurance Device for Helical TomoTherapy

C Chen, J Meadows, T Bichay*, The Lacks Cancer Center at Saint Mary's Health Care, Grand Rapids, MI.

Purpose: We have characterized TomoDose (Sun Nuclear Corp.), a daily QA device for TomoTherapy, which monitors in-plane and cross-plane beam profiles as well as machine output. These parameters were tracked over a one-year period to determine the stability of the device.
Method and Materials: Daily measurements were carried out over a one-year period. The data included in-plane, and cross-plane measurements with TomoDose and ion chambers. Periodic measurements with a water scanner and film profiles were also carried out for comparison. For consistency, these measurements were carried out at equivalent depths. An Exradin A1SL chamber was used for the point dose measurements, and a TomoScanner (Standard Imaging) water scanning systems used for profile verification. Kodak EDR2 film was also used for profile verification. Machine profile analysis using TomoDose, as well as film/water scanning comparisons, were carried out using DTA criteria (distance to agreement criteria of VanDyk et al). **Results:** TomoTherapy Output varied by +/- 1.75% based on TomoDose output analysis and by +/- 1.56% based on ion chamber measurements. In-plane profile analysis indicates that 100% of the DTA are less than 4 mm and 95% less than 3 mm. Cross-plane profile analysis indicates that 100% of the DTA are less than 3 mm. TomoDose retained its calibration for approximately 8 months after which recalibration was required. There is a significant linear relationship ($P<0.01$) between TomoDose unit and ion chamber outputs based on SPSS correlation analysis. **Conclusion:** TomoDose accurately predicted increases and decreases in machine daily variation. The results demonstrate that TomoDose is an acceptable QA device capable of carrying out daily, as well as periodic, verification of TomoTherapy output and profile parameters.

TU-EE-A2-06

A Computer Simulated Study of Dose Optimization Based On Lung Tumor Probability Function Obtained From Long Time Dynamic MRI Scan of Human Subject

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Purpose: To minimize normal lung dose by probability distribution function (PDF) based treatment planning for lung tumors.
Method and Materials: PDFs were obtained from 5 minute dynamic MRI scans of healthy volunteers. The reproducibility of the PDF was validated by repeat scans two to four weeks later. A blood vessel in the lung was identified as "clinical target volume, (CTV)" and tracked automatically to acquire motion trajectories, which were converted to the PDF. The PDF was then incorporated into the objective function of the optimization, which was weighted by the probability of detecting the CTV at a given position. The optimization was performed for a computer simulated phantom with CTV embedded in a cylindrical lung and sequential tomotherapy delivery with beamlet size of 1×2 mm. A series of dose distributions were generated based on different optimization priorities of lung tissue. **Results:** PDF based optimization produced apparently inhomogeneous dose distribution along the CTV motion axis with a peak of 160% of the prescription dose at the low probability end of CTV motion. However, in the moving coordinate, the CTV dose volume histogram failed to show substantial heterogeneity. Compared with conventional optimization, the volume of lung receiving 20% prescription dose was decreased by 44% and the mean lung dose was reduced 9.5% without compromising the CTV dose. **Conclusions and Discussion:** Our optimization algorithm based on a reproducible sequential long dynamic MRI respiratory model reduces both mean lung dose and the volume of lung receiving less than 20% of the prescription dose, which are two of the best predicators of radiation-induced lung toxicity. However, very high dose delivery resolution is required for implementation that for tomotherapy may require a two pass dose delivery strategy with different jaw widths.

Exhibit Hall F

Imaging
Moderated Poster Session
Moderated Poster - Area 3 (Imaging): Image Segmentation, Visualization, and Registration

TU-EE-A3-01

2D-3D Registration of Portal Images with the Planning CT for Detection of Patient Positioning Errors

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Purpose: To compare the use of 2D-3D automatic registration of portal images with the planning CT for detection of patient positioning errors and the use of 3D-3D registration of MVCBCT with the planning CT**.**

Method and Materials: Two prototype programs were used to carry out 2D-3D and 3D-3D image registrations**.** To assess the accuracy and robustness of these programs, 25 sets of 2D portal images, 25 sets of megavoltage conebeam CT (MVCBCT) images with known positioning shifts were acquired**.** A planning CT of the RANDO was also acquired**.** The known shifts between these image sets were ranged from –17mm to 4 mm, -20mm to 5mm and –12mm to 6mm, with uncertainty of 4.278mm, 5.359mm, 3.396mm along the latitude, longitude and vertical directions **Results:** The average differences between 2D-3D method and the known shifts were -0.632±0.318 mm, -0.121±0.437 mm, -0.416±0.346 mm, compared to 3D-3D method of 1.487±0.342 mm, -0.127±0.528 mm, 0.083±0.48 mm along the latitude, longitude and vertical directions**.** The average differences between 2D-3D and 3D-3D image registration methods were 0.86±0.286 mm, -1.39±0.347 mm, -0.33±0.303 mm **Conclusion:** Both 3D-3D and 2D-3D registration methods can detect positioning errors within 1 mm**.** For a rigid body, 2D-3D method is sufficient**.**

Conflict of Interest: This project is partly funded by SIEMENS.

TU-EE-A3-02

Evaluation of a 2D-3D Registration Method for External Beam Radiation Therapy

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Purpose: To implement and validate a 2D-3D registration method for determining 3D patient position in external beam radiotherapy using orthogonal EPID images and megavoltage digitally reconstructed radiographs (MDRRs)**.** To test the methods dependence on cost function, image pre-processing and parameter space sample density, and determine the dependence of registered rotations on setup translations and *vice versa***. Method and Materials:** Orthogonal EPID image of a humanoid phantom in different poses (3D rotations and translations) were acquired in anterior-posterior and latero-lateral view**.** The EPID images were registered with a data base of orthogonal MDRRs, calculated as projection images through the phantom's CT data set at rotation angles within ±5°**.** Registration results were compared for three different cost functions (least-squares, cross-correlation and mutual information), different image pre-processing techniques (unsharp masking, histogram matching) and for isolated and combined rotations and translations**.** The influence of setup translations on registration results for rotations, and *vice versa*, was investigated and compared with a simple model**. Results:** Image pre-processing improves registration precision by more than a factor 2**.** Three dimensional translations were registered with better than 0.5 mm (one standard deviation) when no rotations were present**.** Three-dimensional rotations registered with a precision of better than 0.2° (1 SD) when no translations were present**.** Combined rotations and translations of up to 4° and 15 mm were registered with a precision of better than 0.4° and 0.7 mm respectively**.** Mutual information resulted in the most precise registration**.** Setup translations influence registered rotations, mostly following a simple theoretical model, but not *vice versa***. Conclusion:** Precise registration requires image pre-processing and benefits from interpolation of the parameter space**.** Influence of object translation on registration of out-of-plane rotations can be significant; these "pseudo rotations" can be corrected using the theoretical model when only one projection image is used for registration (e.g**.** fluoroscopy)**.**

TU-EE-A3-03

Automated Segmentation of Radiographic Fiducials for C-Arm Tracking

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Purpose: Intraoperative quantitative C-arm fluoroscopy guidance depends on discerning the relative pose of images (pose recovery)**.** A possible method is to use radiographic fiducials visible in fluoro images [1,2]**.** We propose a robust and fast method for segmenting fiducials designed for brachytherapy applications. **Methods and materials:** The fiducial contains points, lines and ellipses made from BBs and wires[1]**.** The algorithm integrates the a-priori knowledge of fiducial's mechanical construction in a cleverly devised workflow**.** The BB segmentation is achieved using morphological top-hat transform**.** This information serves as a heuristic input to line segmentation realized by a curve tracing algorithm which operates on edge image, followed by augmenting information from intensity image**.** Once the lines are segmented, this information feeds to the ellipse extraction step**.** For ellipse segmentation, intensity image is morphologically processed to eliminate background noise, followed by elimination of BB-s and lines from the information obtained in prior steps**.** The resulting image consists of only ellipse segments**.** A fast variation of Hough transform is used to rectify the full ellipse from the segments. **Results:** The fiducial algorithm identified all the features (BBs, lines and ellipses) visible to human eye in all ten clinical images**.** Next the accuracy of fiducial segmentation was assessed numerically by feeding the results to the pose recovery algorithm of [1]**.** The fiducial was moved on an accurate mechanical platform (as ground truth) while the C-arm was stationary**.** We reconstructed the relative poses with an accuracy of 1.2 mm in translation and 0.3 degrees in rotational based on the segmented fiducials**. Conclusions:** The algorithm makes effective use of a-priori knowledge and combines the techniques of morphological segmentation, curve tracing, and Hough transform, resulting in a novel curve segmentation strategy.

References:

[1] Jain et al, Med Phys 32(10):3185-98
[2] Zhang et al, Phys Med Biol 49**:** 335–345

TU-EE-A3-04

Massive Training Artificial Neural Network (MTANN) to Reduce False Positives Due to Rectal Tubes in Computer-Aided Polyp Detection

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Purpose: One limitation of current computer-aided detection (CAD) of polyps in CT colonography is a relatively large number of false positives**.** Rectal tubes are a common source of false positives and may distract the reader from less common polyps in the rectum**.** Our purpose was to develop a three-dimensional massive-training artificial neural network (3D MTANN) for reduction of false positives due to rectal tubes generated by a CAD scheme. **Material and Methods:** Our database consisted of CT colonography of 73 patients, scanned in both supine and prone positions**.** Fifteen patients had 28 polyps (15 polyps**:** 5-9 mm; 13 polyps**:** 10-25 mm)**.** These cases were subjected to our previously reported CAD scheme that included shape-based detection of polyps and reduction of false positives with a Bayesian neural network**.** With this scheme, 96.4% (27/28) by-polyp sensitivity with 3.1 (224/73) false positives per patient was achieved**.** To eliminate false-positive rectal tubes, we developed a 3D MTANN that was trained to enhance polyps and suppress rectal tubes. **Results:** In the output volumes of the trained 3D MTANN, various polyps were represented by distributions of bright voxels, whereas rectal tubes appeared as darker voxels**.** The 3D MTANN removed all 20 false-positive rectal tubes produced by our original CAD scheme without removing any true positives**.** To evaluate the overall performance, we applied the 3D MTANN to the entire database containing 27 polyps (true positives) and 224 non-polyps (false positives)**.** The 3D MTANN eliminated 33% (73/224) of non-polyps without removal of any true positives in an independent test.**Conclusion:** The 3D MTANN was able to improve the false-positive rate of our original CAD scheme from 3.1 to 2.1 false positives per patient, while an original by-polyp sensitivity of 96.4% was maintained**. Conflict of Interest:** HY, SGA**:** shareholders, R2 Technology, Inc.

TU-EE-A3-05

Current Challenges in DICOM GSDF Calibration For Medical Displays

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Purpose: Over the last few years liquid crystal displays have replaced the traditional light box in medical imaging. When display systems are used for primary diagnosis they need to comply with the DICOM GSDF standard. Previous work already demonstrated that limited grayscale depth and viewing angle dependency of LCD results into lower calibration accuracy. As original contribution this paper investigates the impact of spatial noise and non-uniformities on calibration accuracy. Additionally we will also quantify the relative importance of each of those three shortcomings of medical LCDs. **Method and Materials:** To study the effect of non-uniformity and spatial noise on DICOM GSDF compliance, we compare the observed transfer curve after calibration with the target DICOM GSDF curve and this for multiple locations across the display. The display used is a 5 Mega Pixel monochrome medical LCD display. We also analyze the typical GSDF compliance metrics dL/L and JNDs/step and compare these plots for the other effects of viewing angle dependency and grayscale depth. **Results:** Current calibration practice is to characterize the native transfer curve of the display at only one position (often the centre). However there is significant variation in native transfer curve across the display surface and therefore calibration will only be accurate at the position where the characterization took place. On other display positions the average target luminance distortion compared to GSDF ranges from a few JNDs to over 20 JNDs. A technique of spatial noise-reduction can solve this problem. We also observe that spatial-noise is much more important than viewing angle and grayscale depth for typical usage. **Conclusion:** This paper has demonstrated that non-uniformities and spatial noise can result into poor calibration accuracy. Also a possible solution to the problem has been described. **Conflict of Interest:** Research sponsored by Barco Medical Imaging Systems.

TU-EE-A3-06

Evaluation of a Volumetric Display for Radiation Therapy Treatment Planning

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Purpose: To evaluate an innovative volumetric display for radiation treatment planning applications. **Method and Materials:** A volumetric, auto-stereoscopic display (Perspecta Spatial 3D, Actuality-Systems Inc., Bedford, MA) has been integrated with the Pinnacle[3] TPS for treatment planning. The Perspecta 3D display renders a 25 cm diameter volume that is viewable from any side, floating within a translucent dome. In addition to display all the 3D data exported from Pinnacle, the system provides a 3D cursor and beam placement tools. A 125 point, 5 cm spaced grid centered at isocenter was created in Pinnacle and transferred to Perspecta. A Perspecta 3D ruler verified distances between any two points on the 3D grid. Ten teletherapy beams with various gantry/couch combinations were generated on Pinnacle and verified on Perspecta display. Doses at the same grid points were also compared. CT images from a QUASAR phantom in 3 orientations were used on Perspecta to confirm beam field size, divergence, etc. **Results:** In general, the Perspecta system accurately depicted all 3D data exported from Pinnacle. When measured by the 3D ruler, distances between any two points using Perspecta agreed with Pinnacle within the measurement error (typically <0.5 mm). Beam angles were verified through Cartesian coordinate system measurements and also upon rotating the phantom. Field sizes, collimator angles, and beam divergence were similarly confirmed. Isodose surfaces and dose values chosen at arbitrary locations in Perspecta agreed with Pinnacle within ± 2% in an absolute sense, which was governed by human error in coinciding the points. **Conclusions:** These preliminary results indicate that the Perspecta device is capable of displaying consistent data from the Pinnacle radiotherapy treatment planning system, and may become a valuable tool for visualization and quantitative evaluations in radiation oncology. **Conflict of Interest Statement:** Actuality Systems Inc. provided the 3D display used in this study.

Exhibit Hall F

Imaging
Moderated Poster Session
Moderated Poster - Area 4 (Imaging): Imaging Dosimetry and Quality Control

TU-EE-A4-01

Impact of Hardware Errors and Patient Movement On Standardized MR QA Tests for Noncartesian Pulse Sequences: Are These Standard QA Tests Sufficient ?

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Purpose: The American College of Radiology (ACR) phantom was designed during a stage when most pulse sequences were rectilinear. Noncartesian trajectories (including Projection Reconstruction and Spiral imaging) are becoming more widely available on most standard clinical scanners. Our goal was to assess if either 1) ACR quality assurance (QA) tests, 2) Root Mean Square Error (RMSE), or 3) by Visual Inspection, or a combination of the above methods would adequately assess the types of image artifacts associated with these radial methods. **Method and Materials:** Simulation in Matlab and C was written to reconstruct ACR phantom images using projection and spiral methods. Additive and multiplicative phase distortions and as well as center of k-space misregistration artifacts were introduced to test their impact on phantom images for both reconstruction methods. Additional artifacts of gradient delay, amplitude modulation and miscalibration of gradient amplitude were tested for spiral reconstruction. Images were then evaluated using the above mentioned techniques. **Results:** Gradient delay, miscalibration of gradient modulation and k-space center misregistration affected all tests. However, the ACR QA test did not effectively demonstrate the influence of certain artifacts (phase distortion artifacts and ghosting) in projection and spiral reconstructed images. RSME was effective for most tests in determining the overall severity (i.e. larger RMSE demonstrates more artifacts). However, RMSE was not useful for assessing phase distortion. **Conclusions:** We noted that for specific artifacts, QA and RMSE tests were not sufficient alone. Visual inspection is time consuming, but is not necessarily a true objective test of performance as ACR QA. A compendium of noncartesian induced hardware artifacts was generated for Physicist Referral and we believe a combination of all above methods 1) ACR QA, 2) RMSE and Visual Inspection would be the appropriate test for validating scanner performance.

TU-EE-A4-02

Some Issues With Image Intensity Uniformity Test Performed On 3T MRI Scanners

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Purpose: To investigate why Image Intensity Uniformity (IIU) tests performed on commercial 3T MRI systems according to the ACR MR Accreditation Program (MRAP) instructions are subject to frequent failures. **Method and Materials:** The phantom scanning instructions for ACR MRAP tests specify that a dedicated phantom (ACR phantom) must be used to assess the MRI scanners performance. As a part of required test, an assessment of IIU is performed by measuring the Percent Image Uniformity (PIU) according to the specified formula. The data used in calculation of PIU must be acquired for a rigidly defined scanning protocols, and the process of data collection is also precisely specified. For the 3T MRI scanner to pass the test, the measured PIU must be equal or greater than 82%.

PIU tests were performed using the same ACR phantom on five different 3T MR scanners from two different vendors, following the ACR MRAP acquisition and measurement protocol exactly. The scanners tested were installed in routine clinical settings and all head coils, available on site, were tested independently. In addition, if scanner offered multiple gradient performance modes, all modes were tested. Finally, effects of image post-processing routines, designed to improve the image uniformity and installed on the scanners were investigated as well. **Results:** A vast majority of PIU tests using non-postprocessed images failed (more than 95%). All tests that used postprocessed images passed. Upon closer investigation, the likely cause of failures was linked to RF properties of the

ACR phantom. **Conclusion:** The IIU test needs to be carefully reassessed to ensure that it provides a meaningful characterization of MRI scanner's performance, and is not hampered by the limitations imposed by the electromagnetic physics of scanning at 127 MHz, the resonant RF frequency of 3T MRI systems.

TU-EE-A4-03

Quality Control Testing of Diagnostic Ultrasound Systems: Experience in Testing 72 Systems in 11 Years

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Purpose: The goal is to assess the necessity and relevance of QA/QC testing procedures for diagnostic ultrasound systems. **Methods and Materials:** The ultrasound QA/QC program at our institute was reviewed in this paper. Over the past 11 years, 72 diagnostic ultrasound systems have been included in the QA/QC program. Acceptance tests were conducted in newly installed systems. In some situations, final payment was withheld to ensure the correction of the deficiencies revealed during the acceptance testing. Periodic QC reports were sent to the in-house engineer group and corrective actions were taken and documented. Our testing procedures included B-mode tests on distance accuracy, maximum depth of penetration, spatial resolution, contrast lesion detectability, image uniformity, dead zone, image display/soft copy fidelity and other physical and mechanical inspections. In addition, Doppler mode tests were performed on some units to measure the Doppler signal sensitivity, angle accuracy, gray-scale image congruency, range-gate accuracy and flow readout accuracy. **Results:** A total of 84 deficiencies were documented on those units older than 5 years (1.8 deficiencies/unit-year) and 183 deficiencies on the units with ages of 5 years or less (1.0 deficiencies/unit-year). These problems were classified in categories according to the QC tests and the percentage distribution of each category was calculated. While the overall image quality deterioration revealed through spatial resolution and contrast lesion detectability testing topped the deficiency category list for older units, a significant increase in transducer deficiencies was observed on newer modern state-of-art units. This observation was consistent with the increasing complexity in rapidly advancing transducer technology in recent years. QA/QC procedures appeared able to reveal problems at their early stage before these problems would severely interfere with clinical practices.**Conclusion:** This experience of ultrasound QA/QC program at our institute confirms the necessity to have a comprehensive QA/QC program for diagnostic ultrasound systems.

TU-EE-A4-04

Comparison of the CT Scatter Fractions Provided in NCRP Report No. 147 to Scanner-Specific Scatter Fractions and the Consequences for Calculated Barrier Thickness

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Purpose: NCRP Report No. 147 provides fixed values of the scatter fraction per centimeter (κ) for the peripheral axis of the head and body CT phantoms. This study was performed to determine scatter fractions for different makes and models of CT scanner and to examine the consequence of any differences in κ on a typical shielding calculation. **Method and Materials:** κ values for five GE CT models, four Siemens CT models and one Toshiba CT model were determined. They were calculated using an equation for the scattered air kerma at 1 m from NCRP 147 ($Kerma_{scatter}=\kappa*ScanLength*CTDI_{100}/pitch$) and using scattered air kerma data provided by the manufacturers and measured $CTDI_{100}$ (periphery) values. Typical barrier calculations, following NCRP 147 methodology, were performed for each CT scanner using the fixed κ values and, separately, using the calculated scanner-specific values. **Results:** The κ values from NCRP 147 are $3x10^{-4}$/cm and $9x10^{-5}$/cm for the periphery of the body and head phantoms, respectively. Calculated κ values varied from $3.2x10^{-4}$ to $5.2x10^{-4}$/cm for the body and $5.6x10^{-5}$ to $1.1x10^{-4}$/cm for the head. The results of a typical barrier calculation indicate that for the scanners studied, the fixed κ values produced lead barrier thicknesses that ranged from 0 to 0.2 mm less than those determined from scanner-specific κ values. Similar calculations for the floor gave a maximum underestimate of 1.2 cm. **Conclusion:** The actual κ values of a specific CT scanner can vary significantly from the fixed values provided in NCRP 147. Using the fixed values for some scanners may slightly underestimate the required barrier thickness. Any small underestimate in barrier thickness would likely be more than compensated by a conservative estimate of the scanner's workload.

TU-EE-A4-05

Monte Carlo Calculation of the Organ and Effective Doses for Pediatric Patients Under Helical CT Exams

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Purpose: As it gains more popularity as a diagnostic modality, helical multi-slice CT can potentially impose a significant patient dose especially to pediatric populations. Even though simple acryl phantoms have been used to estimate relative radiation risks to the patient, very few studies have investigated accurate age-dependent organ absorbed doses. This study was intended to assess individual organ dose as well as the effective dose under typical CT exams using realistic tomographic phantoms of pediatric patients. **Method and Materials:** Five ORNL stylized phantoms and five realistic UF tomographic phantoms of pediatric patients were prepared for the use with MCNPX general Monte Carlo code. A FORTRAN subroutine was written to explicitly simulate the helical motion of the multi-slice CT x-ray source. Ion chamber measurements provided the normalization factors for the Monte Carlo simulation results. Three tube voltages (80 kVp, 100 kVp, and 120 kVp), two collimated beam thicknesses (12 mm and 24 mm), and two filter (head filter and body filter) combinations were simulated for each of the ten phantoms. **Results:** The study data showed that the effective dose increased on average 110% when the tube voltage changed from 80 kVp to 100 kVp at the same tube current setting, while the 120 kVp imposed on average 53.8% higher dose than the 100 kVp tube settings in the CAP CT exams. The ORNL phantoms and the UF phantoms showed distinctive dosimetric characteristics under chest and abdomen CT exams. The cause of these differences is explained by the unrealistic torso thicknesses of the ORNL stylized phantoms. Individual organ equivalent doses are also calculated and compared between the two types of phantoms. **Conclusion:** Detailed organ doses and effective doses were calculated for pediatric patients under helical CT using various anthropomorphic computational phantoms and Monte Carlo code.

TU-EE-A4-06

Analysis of Dose-Related Data Logged for Fluoroscopic Cardiac Interventional Procedures

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Purpose: In response to FDA advisories of the potential for skin injuries from fluoroscopically-guided interventions, logs have been recorded of procedure-related information for all fluoroscopic cardiac studies performed at our hospital. The data includes dose-area product (DAP), estimated entrance-skin dose (ESD), fluoroscopy time, number of digital runs, image-intensifier magnification mode, and patient weight and height as well as procedure type and physician. **Method and Materials:** Dose-related data was recorded for over 2000 cardiac catheterization and over 800 electrophysiology procedures. This information was transferred to a database spreadsheet and analyzed to determine distribution shape, range and median values and correlations between factors. ESD values were calculated from DAP readings using the estimated field size at the patient entrance and included backscatter. Fluoroscopy times and dose values are compared by procedure and physician. Those procedures evaluated included percutaneous-coronary interventions (PCI) performed in the catheterization laboratory and radiofrequency ablation (RFA) and biventricular-implantable-cardioverter defibrillator (BIV ICD) placement performed in the electrophysiology lab. **Results:** All procedures had a wide range of DAP values, ESD values and fluoroscopy times with distributions skewed toward the lower end. PCI procedures generally had the greatest ranges (216 to 88,971 cGy-cm^2 DAP, 2 to 726 cGy ESD, 1 to 96 minutes fluoroscopy) and the highest median values (16,000 cGy-cm^2, 130 cGy, 20 minutes). There was some correlation demonstrated between DAP values and fluoroscopy time and patient body mass index. ESD values calculated from DAP values had a large uncertainty primarily due to uncertainty in the exposure geometry.**Conclusion:** Although an inexact measure of skin exposure during interventional procedures, DAP values provide some guidance in identifying those patients with ESD values potentially above thresholds for deterministic effects. Tracking of this

parameter can provide an indicator of when cautionary notes should be placed in the patient's chart for medical observation and followup.

Imaging Scientific Session Room 330D
Imaging Dosimetry

TU-E-330D-01

TLD-100 Measurement and Assessment of Internal Mouse Dosimetry During Micro-CT Analysis

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Purpose: Because Micro-CT utilizes ionizing radiation for image formation, radiation exposure during imaging is a concern. The objective of this study is to quantify the radiation exposure delivered during a Micro-CT scan and to assess potential therapeutic effects associated with this radiation dose in a murine cancer model. **Materials and Methods:** Radiation exposure was measured using calibrated thermoluminescent dosimeters (TLD-100) irradiated during a typical Micro-CT scan protocol. TLD calibration curves were generated with a Cs-137 irradiator. TLD's were implanted into a euthanized mouse and was imaged with Micro-CT. TLD's were removed post–scan and analyzed. Internal exposures were converted to dose in water. A C57BL/6 mouse lung tumor model derived by IV injection of 400,000 B16F10 murine melanoma cells was assessed for survivability and potential therapeutic effects due to absorbed radiation doses during Micro-CT imaging. **Results:** A single Micro-CT scan dose of 7.8±0.5 cGy was achieved when using a lucite anesthesia support module and a dose of 9.2±0.6 cGy with out the use of the anesthesia module. TLD data was validated using an ion chamber, providing measured radiation exposures of 8.1±0.4 cGy and 9.7±0.5 cGy with and with out the anesthesia module, respectively. Internal TLD analysis demonstrated an average mouse organ absorbed dose of 7.3±0.6 cGy. **Conclusions:** Survival analysis demonstrated a mean survival of non-treated control animals of 29±2 days, with animals receiving up to five sequential Micro-CT studies surviving a mean of 30.5±1.5 days (total estimated dose of 39±2.5 cGy).The calculated cell survival fraction for a 9.2 cGy Micro-CT scan was 99.25%. Therefore, negligible therapeutic effect from the radiation exposure delivered during Micro-CT analysis was observed in the animal model investigated.

TU-E-330D-02

Monte Carlo Simulation to Assess Fetal Dose From MDCT Imaging Using Patient Based Voxelized Models

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Purpose: To use detailed Monte Carlo simulations to investigate fetal dose from a multidetector CT (MDCT) using voxelized models created from actual patient images including early and late term pregnancies. **Method and Materials:** Detailed voxelized models of anatomy were created based on image data from a cohort of pregnant patients who had previously undergone abdomen/pelvis CT scans. The gestational ages ranged from less than 5 weeks to 33.7 weeks. Three regions, corresponding to fetus, gestational sac, and uterus, were contoured on each image series by a radiologist.

A MDCT model was created using details about the source spectra, filtration, collimation, and geometry. To simulate an actual scan, a helical source path was defined and particles were transported through the anatomy of the voxelized patient models; radiation dose was tallied in voxels belonging to the three regions of interest. The simulated abdomen/pelvis scan used a helical scan of 120kVp, pitch 1, and 4 x 5 mm total nominal beam collimation.

Dose on a per mAs basis was separately calculated for the fetus when the fetus was distinguishable from the gestational sac and uterus in the original image. These doses were then compared to two generally accepted fetus dose estimations: the Felmlee et al method and the ImPact estimation of dose to a uterus (for fetuses < 8 weeks). **Results:** The radiation dose to the fetus in the models with gestational ages of <5 weeks, 6.6 weeks, 7.1 weeks, and 28.3 weeks, were 8.31 mGy/100mAs, 9.67 mGy/100mAs, 14.22 mGy/100mAs, and 11.70 mGy/100mAs, respectively. The fetus dose estimate using the Felmlee technique was 11.30 mGy/100mAs. The ImPact dose estimate to a fetus was 13.0mGy/100mAs. **Conclusion:** Radiation dose to the fetus was successfully estimated at different gestational ages using detailed models of actual patient and fetus morphology, scanner geometry, and acquisition protocols.

TU-E-330D-03

Evaluation of An OSL Dosimetry System for CT Quality Assurance and Dose Optimization

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Purpose: Recent development of wide-beam multidetector CT and cone-beam CT demands alternative methodology to CTDI. In this study, the Optically Stimulated Luminescence (OSL) technique was evaluated for CT quality assurance and dose optimization. **Method and Materials:** CT scans were performed on 38-mm^2 thin Luxel^{TM} Al_2O_3:C dosimeters oriented in axial plane of a GE LightSpeed Ultra and at the center of a CT body dosimetry phantom. A 5-mm beam collimation was selected to determine the energy response of the OSL detector at 80, 120, and 140 kVp stations. mA response of the OSL detector was evaluated from 60 to 350 mA. Helical scans of varying length coverage were also performed with the detector placed at the isocenter. The exposed OSL discs were measured using a Riso TL/OSL-DA-15 reader. Each OSL measurement was followed by a standard beta source irradiation and subsequent OSL measurement to normalize for the differing mass of the disks. The normalized OSL signal reading was used in the data analysis. **Results:** Good mA linearity was observed at all 3 kVp stations. There are discontinuities seen at ~ 250 mA and it is known to be caused by tube focal spot change. The 120 and 140 kVp data show good correlation with ionization chamber reading. For 80 kVp, OSL signals to ion chamber readings are all higher, particularly at low mA range, indicating higher sensitivity of the OSL detector over the ion chamber. The helical scans show an increased OSL signal with scan length and a leveling of the signal at large scan coverage. **Conclusion:**
The OSL detectors are of small size and responded well to CT exposure. It provides a practical technique for quantifying the dose at any location of a phantom for quality assurance and hence exhibits a potential for estimating patient organ dose.

TU-E-330D-04

Estimation of Cardiologists Radiation Doses Received During Interventional Examinations

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Purpose: The aim of this work is to suggest a simple method for the estimation of cardiologist extremity doses. **Method and Materials:**
The extremity and effective doses of nine cardiologists working at five different angiographic units were measured for 157 interventional examinations. Simultaneous measurement of patient doses were also carried out using a DAP meter separately for each projection. Fluoroscopy time (T_{fl}), number of radiographic frames (N_{rf}) were recorded on-line during these measurements.. A Rando phantom was exposed at similar projections with patient studies and one minute of fluoroscopic exposure ($DFL_{x,n}$) and one frame of radiographic exposure ($DRN_{x,n}$) were determined for each projection. Scatter radiations from these exposures were also measured at 50, 100 and 150 cm above the floor level at the cardiologist positions for the estimation of legs, wrists and thyroid (or eye) doses. Weighting of projections were determined for the patient group of each cardiologist using the recorded values of T_{fl} and N_{rf}
Extremity doses, D_x were calculated from the following formula:

$$D_x = \sum_n DFL_{x,n} \cdot T_{fl} + \sum_n DRN_{x,n} \cdot N_{rf}$$

n gives the projection number and x is the distance from the floor level. **Results:** Measured and calculated extremity doses for each cardiologist were in good agreement (R= 0.75 for thyroid). The calculated doses for

50cm and 100cm were found within the measured values of left and right legs and wrists. The use of dominant projection data alone still provided comparable results. **Conclusion:** If there is a lock of personal dosimetry for cardiologists, it could be possible to make an estimation of extremity doses from the of total fluoroscopy time and frame numbers used in the examinations together with the knowledge of scatter radiations at cardiologist positions.

TU-E-330D-05

Potential Radiation Guidance Levels for Invasive Cardiology

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Purpose: An International Atomic Energy Coordinated Research Program investigated the feasibility of providing guidance levels for fluoroscopically guided invasive cardiology procedures. **Method and Materials:** A sample of 6,000 cases of coronary angiography (CA), coronary angioplasty (PTCA) or combined CA and PTCA from ten laboratories in four different countries were used for the analysis. Dosimetric and patient demographic data were collected. Intercalibration of kerma area product (KAP) meters and quality control tests were periodically performed. Image quality and skin dose distributions were evaluated in a small sample of procedures. Procedure complexity was evaluated in a subset of 1,000 PTCA cases. **Results:**
Classification into three clean categories proved difficult due to the rapid evolution of interventional cardiology and considerable variability in routine clinical practice among the centers. It may be better to categorize cases as either coronary angiography only (DX) or interventional, with a variable CA component (RX).

Median values of KAP (for similar procedures) varied by a factor of three between centers. Complexity has a factor of two influence on KAP. The data suggest that a laboratory can normalize its data by complexity scaling.

Dose inefficient laboratories were identified by noting that the median value of procedures exceeded the third-quartile value for the entire pool. One laboratory exceeded the guidance level because of the use of 25 fps imaging in place of the more common 12.5 fps. Another laboratory, not under routine QA testing, had high fluoroscopic and cinefluorographic dose rates. **Conclusion:** Guidance levels for invasive cardiology appear to be feasible. Suggested KAP guidance levels for a facility performing procedures of moderate complexity are 50 $Gycm^2$ for DX and 120 $Gycm^2$ for RX. These values should identify dose inefficient laboratories. Guidance for fluoro time and cine frame count is being developed. Further research is needed as clinical procedures and technologies evolve.

TU-E-330D-06

Assessing Patient Radiation Exposure From Fluoro-Guided Procedures Based On Direct Dose and Dose-Area Products

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Purpose: To assess patient radiation exposure from fluoro-guided procedures based on direct dose and dose-area product. **Method and Materials:** Various procedures performed by members of Cardiology and Radiology Departments at SUNY Stony Brook were monitored for radiation exposure to patients' skin. Dose, dose-area product, fluoro-time, and beam parameters were recorded for each fluoro-cine run. Along with clinical data, dosimetry print-out was reviewed after each procedure to identify possible high doses to any given site of the exposed area and to have appropriate medical care provided timely. Accrued data were analyzed and evaluated in detail. **Results:** Data from a total of 3040 consecutive cases, 1883 diagnostic and 1157 interventional, performed by 16 and 10 physicians respectively were analyzed. Based on dosimetry print-out, the total skin dose averaged 87 rads for diagnostic procedures, with maximum skin dose below 100 rads to any given site found in over 90% of cases, that for interventional procedures respectively were 223 rads, with maximum skin dose over 300 rads to any given site found in over 15% of cases. **Conclusions:** Our experience demonstrated the value of careful monitoring and thorough assessment of radiation dose and dose distribution in keeping medical staff informed timely of their patients' exposures.

TU-E-330D-07

The Effect of Subcutaneous Fat On Patient Effective Dose in Diagnostic Radiology

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Purpose: To quantify the dependence of effective dose on subcutaneous fat thickness in x-ray radiography and develop a set of relative radiation risk factors for comparing overweight to "lean" patients. **Materials and Methods:** Using the MCNP Monte Carlo code and geometric phantoms patterned after Christy *et al*, effective dose calculations were performed for abdominal and chest radiographs of a "normal weight" adult male phantom. The effective dose, E_o, was normalized to the number of x-rays exiting the patient to model a constant exposure to the image receptor. Varying thicknesses of adipose tissue were then added to the anterior, lateral, and /or posterior regions of the torso of the phantom and the normalized effective dose, E, calculated at the same kVp and source to image receptor distance. The ratio E/E_o provides an index of the increased stochastic risk. Anterior:lateral:posterior fat ratios used ranged from 6:5:1 to 1:3:6 with total anterior plus posterior additional fat thicknesses extending from 1 to 30 cm. **Results:** For AP and PA projections, both the lateral fat and the fat layer proximal to the x-ray beam had negligible effect on E/Eo. E/Eo was shown to depend only on the *distal* fat layer thickness with an exponential dependence of the form exp(kx), where k is an exam/kVp specific constant, and x the distal fat layer thickness. For the AP abdominal projection, k values were 0.127, 0.119, 0.106, and 0.094 cm^{-1} at 80, 100, 120, and 140 kVp, respectively. R^2 for all fits were better than 0.96. E/Eo ranged as high as 12.4 for an extremely obese patient with 20 cm of posterior fat at 80 kVp. **Conclusions:** Overweight and obese patients incur significantly elevated stochastic risks from radiographic procedures as compared to their lean counterparts, depending upon the kVp and fat layer thickness closest to the image receptor.

Professional Panel Room 230A

ABR Maintenance of Certification Update

TU-E-230A-01

Panel: ABR MOC Update

S Thomas*[1], B Paliwal*[2], R Morin*[3], M Yester*[4], (1) Univ Cincinnati Medical Center, Cincinnati, OH, (2) University of Wisconsin, Madison, WI, (3) Mayo Clinic, Jacksonville, FL, (4) UAB Medical Center, Birmingham, AL

In March 2000, the twenty-four member boards of the American Board of Medical Specialties (ABMS) formally agreed that all boards would develop programs for Maintenance of Certification (MOC). In some cases, MOC would be replacing existing or evolving programs for recertification of diplomates. As initiated by The ABR in 2002, certification in the 3 categories of Radiologic Physics (Diagnostic Radiologic Physics, Therapeutic Radiologic Physics, and Medical Nuclear Physics) is time limited to 10 years. To retain certification beyond that period, the individual must engage in The ABR MOCP for medical physicists. Under the ABMS format, MOC has 4 components: 1.) Professional Standing, 2.) Lifelong Learning and Self-Assessment, 3.) Cognitive Expertise, and 4.) Evaluation of Practice Performance. For medical physicists, professional standing will be evaluated through documentation of licensure where applicable, otherwise through letters of attestation. Life Long Learning entails requirements for CME Category 1 credits with optional participation in Self Directed Educational Projects (SDEPs). Self-assessment is accomplished through completion of a series of Self-Assessment Modules (SAMs) that are also Category 1 approved activities that will count as well toward the Lifelong Learning credits. Cognitive expertise will be assessed once toward the end of the 10-year cycle through a proctored, secure examination administered at a national testing center and will consist of multiple choice questions involving a.) core knowledge fundamental to the practice of radiological physics, and b.) new updated information and

emerging technology. Performance in Practice Evaluation (PPE) assessment methodologies for medical physicists are evolving (as they are for our physician colleagues) and will be focused on the radiologic physicist as a medical professional who contributes to and supports patient care within the healthcare system, while not having primary responsibility for the patient. To facilitate record keeping and maintaining documentation for the MOC process, a web-based, password-protected system is being established for diplomate use. All information required would be submitted to The ABR in the final year before expiration of the certificate. Upon positive review, a 10-year extension of certification would be issued. The session format will be that of an interactive forum in which the panel will review specific details of the 4 MOC components, provide concrete examples of the processes associated with each component, outline the procedures being implemented to facilitate the MOC process for medical physicists, and define the time lines for candidates currently on the MOCP track. In addition, the activities of the AAPM Task Group on MOC in assisting diplomates as they move through the MOCP will be described. There will be opportunity for candidates, prospective diplomates, and other participants to ask questions that would enhance their understanding of the process and assist their transition into The ABR MOCP.

Educational Objectives:
1. To understand the components of The ABR Maintenance of Certification Program (MOCP) as required for medical physicists.
2. To understand the process by which the medical physicists may complete The ABR MOC program.

Therapy Continuing Education Course Valencia A
CE: IMRT Site Specific - II: H&N, CNS

TU-E-ValA-01
IMRT of the Central Nervous System
M Munley*, V Stieber, Wake Forest Univ. School of Medicine, Winston-Salem, NC

Intensity modulated radiation therapy (IMRT) for the central nervous system (CNS) is being used more frequently in radiation oncology clinics. There are two general situations that the treatment of CNS disease may benefit from the use of IMRT compared to conventional, three-dimensional conformal radiation therapy: 1) when multiple critical structures confined within the intracranial vault are to be avoided, one may desire an optimal dose distribution that allows for the dose to these structures to be minimized, and 2) since high-grade gliomas tend to recur locally, IMRT should allow for dose escalation proportional to the corresponding heterogeneous cell populations. Based on the anatomic location of the treatment volumes, one can visualize examples where IMRT could be of benefit. Patients with a concave or irregularly-shaped target in a frontal lobe may require IMRT in order to spare the adjacent globe and any uninvolved optic apparatus. In patients with well-lateralized tumors involving the brain parenchyma, complete sparing of the contralateral hemisphere is desirable. Patients with infiltrative gliomas traditionally have large margins placed around the treatment volumes, and these may often encompass uninvolved critical normal structures. For such cases, IMRT may allow for non-uniform reduction of the treatment volume around these normal structures. The primary goal of this presentation is to provide a practical overview of IMRT for the CNS.

Though much attention has been given to the inverse planning and quality assurance aspects of IMRT, one should have an adequate understanding of the entire process; from proper patient selection to positioning/immobilization and continuing through treatment. A discussion of the steps of the CNS IMRT process will include: patient selection, immobilization, recommended imaging acquisitions, structure delineation, planning strategies/parameters, dose objectives, plan evaluation, QA, and potential delivery issues. Guidelines and practical examples for each component of this process will be presented.

To gain further familiarization of CNS IMRT, one should review the corresponding technological and clinical outcome literature. Comparisons to conventional radiotherapy methods will be examined in terms of technique, dosimetry and clinical outcome. Finally, current research and future directions of CNS IMRT will be introduced such as the novel use of sophisticated imaging techniques for improved structure definition, patient positioning and dose modulation.

Educational Objectives:
1. To understand the general practice of CNS IMRT from patient selection through actual treatment.
2. To become familiar with specific details pertaining to the CNS IMRT process through several illustrative examples.
3. To be introduced to some of the research and future directions of CNS IMRT.

Research supported, in part, by Varian Medical Systems.

TU-E-ValA-02
IMRT for Head and Neck
T Pawlicki*, Stanford Univ School of Medicine, Stanford, CA

The purpose of this presentation is to discuss key issues in IMRT treatments for head and neck cancers. Experience has matured over the past several years in this regard. The main focus will be on the details related to the planning process such as, immbolization, imaging and setup management, treatment planning, and plan evaluation. An emphasis will be given to describing one institution's implementation of a head and neck IMRT program with a lesser emphasis on a review of the relevant literature. The conformal nature of IMRT dose distributions requires additional consideration on the degree of immbolization and expected reproducibility of setup. Custom neck molds, masking systems and additional shoulder constraints are required to maximize reproducibility of the head, chin, and clavicals (supraclavicular nodes). Even with these constraints, daily variability can be expected and the treatment plan should account for those effects. New localization tools such as on-board kV planar imaging and cone-beam CT are becoming available to aid in localization and patient set-up. The use of these new techniques will be described. Target and normal tissue segmentation are very important in the planning process and must be considered in detail by the physicist. Various imaging modalities are frequently used. Contrast enhanced CT and MRI-CT fusion is useful for primary tumor segmentation. Fused ^{18}FDG PET-CT images can be used to identify positive neck nodes but lack anatomic definition and are not always useful for defining the primary tumor. Before treatment planning begins, a quick but pertinent conversation with the treating physician is necessary to clearly understand the dose/volume tolerances of normal tissues and other patient-specific issues (e.g., previous treatment, chemotherapy, or already compromised tissues). This dialogue with the physician helps to limit the iterations of optimization and dose evaluation to efficiently arrive at the best IMRT plan. Once treatment planning begins there are many more techniques at the physicist's disposal to develop the best treatment plan compared to conventional planning. Each of these will be discussed. Evaluating IMRT plans is a determination of tradeoffs. An important principle regarding target coverage is the trade-off between dose conformity and dose heterogeneity across the target. If the plan emphasis is conformity to the target, then one should accept increased dose heterogeneity and vice versa. It is absolutely essential to be realistic in the expectations of IMRT and be prepared to accept some dose to critical structures (but keeping them below tolerance) in order to get better target coverage than a conventional plan would provide. Detailed slice-by-slice evaluation of isodose coverage for the location and magnitude of hot and cold spots is essential during plan evaluation. Before starting treatment, a set-up verification step is typically helpful, during which the immobilization system and isocenter location are checked. Orthogonal DRR images of the isocenter(s) location can be reproduced by simulator images for better visualization of bony landmarks. Kilovoltage and cone-beam CT imaging techniques are more prevalent in the treatment room for this purpose. For on treatment set-up verification, utilizing digital images and associated software tools can help to accurately identify isocenter translations and patient rotations (head or shoulder tilt).

Educational Objectives:
1. Understand issues related to patient immobilization.
2. Identify normal tissues and know their dose/volume constraints.
3. Describe several planning techniques to achieve the best dose distribution.

Therapy Scientific Session Room 224A
Stereotactic, Single and Hypofractionated Treatment II

TU-E-224A-01
Evaluation of Heterogeneity Corrections Algorithms Through the Irradiation of a Lung Phantom

P Alvarez*, A Molineu, N Hernandez, D Followill, G Ibbott, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: To evaluate the impact of applying heterogeneity corrections to the calculation of prescribed doses to a target located within the lung. **Method and Materials:** The Radiological Physics Center's (RPC) anthropomorphic lung phantom was sent to institutions nationwide. This phantom simulates a patient not only in dimensions but also in densities for imaging and treatment purposes. This design includes two lungs with density of 0.33 g/cm^3 and a target centrally located in the left lung with density near 1 g/cm^3. TLD and radiochromic films were used as dosimeters within and near the target region. Institutions that received the phantom were requested to image, plan and treat the phantom as if a patient. The prescription dose, based on a stereotactic plan, was 20 Gy to the target, calculated without applying heterogeneity corrections. The institutions were asked to submit both the homogeneous and heterogeneity corrected treatment plans using the same number of monitor units. **Results:** Twenty-one irradiations, mostly with 6 MV x-rays, were analyzed from 7 different Treatment Planning Systems (TPS). The ratio of dose to the target from the plan with to the plan without heterogeneity corrections was calculated and analyzed based on the algorithms used for the heterogeneity correction. A comparison of corrected dose given by the TPS and dose given by TLD was performed. The average ratio between dose with to dose without the heterogeneity correction was 1.18 with values ranging from 1.12 to 1.21. The superposition convolution algorithms agreed better with measurements than the other algorithms studied. The average TLD/Inst dose ratio in the target was 0.97 ranging from 0.92 to 0.99. **Conclusions:** There continues to be a differences in the heterogeneity corrected tumor doses within the lung from different planning systems.

Work supported by PHS grant CA10953 and CA081647 from the NCI, DHHS.

TU-E-224A-02
Dosimetry of Very Small (1.5 and 3 Mm Diameter) Photon Beams: Diode and Film Measurements Versus Monte Carlo Calculations

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Purpose: To measure the dosimetric parameters of 10 MV photon beams in 1.5 and 3 mm diameter fields with a small-field diode, radiographic XV film, and radiochromic HS film, and to compare measured data with the same parameters calculated by Monte Carlo (MC) simulations. Methods and Materials: A 10-MV Clinac-18 linac was used as the radiation source and the very small diameter fields were set up with radiosurgical collimators. PDDs, profiles, and output factors of the very small photon beams were measured with diode/water tank and film/scanner techniques. The measured parameters were compared against those calculated by MC simulations using an experimentally determined circular source diameter of 1.5 mm in beam modeling. For improved accuracy, the PDDs were measured with the diode and the water tank using beam profile scans. A document scanner was used as film densitometer to offer high spatial resolution (254 lpi) required in very small photon field dosimetry. **Results:** PDDs measured by the diode agree well with the MC-calculated results, within ± 2% and ± 3% in 3 and 1.5 mm fields, respectively. Lateral profiles measured by the diode and film generally agree with MC calculations, but significant discrepancies are observed in the tail portion of the 1.5-mm beam profile. Relative dose factors obtained by averaging the diode, HS film, and MC results are 0.22 ± 0.01 and 0.43 ± 0.01 for the 1.5 and 3 mm fields, respectively. **Conclusion:** Based on the good agreement between the measured and MC-calculated dosimetric parameters for the 1.5 and 3 mm diameter, 10 MV beams, we conclude that MC calculations can be used in general for dosimetry of very small photon fields, provided that the physical source size of the linac is correctly measured and used in the MC simulations.

TU-E-224A-03
Image and Dosimetric Verification of Positioning Accuracy for Helical Tomotherapy Intensity Modulated Stereotactic Radiosurgery

A Liu*, C Han, C Staud, S Sun, T Schultheiss, J Wong, City of Hope National Medical Center, Duarte, CA

Purpose: To investigate the accuracy of Helical Tomotherapy for intracranial radiosurgery using Mega-voltage CT (MVCT) image fusion. **Method and Materials:** Tomotherapy generates a set of MVCT images which are fused to the treatment planning KVCT to facilitate the patient setup. For intracranial lesions, mutual information matching program using bony anatomy automatically generates the lateral, longitudinal, vertical, pitch, roll and yaw adjustments that are necessary to align the MVCT to KVCT images. In our study, a *pReference* head phantom immobilized by Nomos Talon system was used to verify the positioning accuracy of MVCT fusion. Three gold-filled titanium markers inside the head phantom and the localization tip in the Talon system were used as the independent imaging makers to verify the MVCT positioning accuracy. In addition, dosimetric analysis was performed with a 0.015cc pinpoint ion chamber placed inside the phantom during KVCT simulation. A tomotherapy SRS plan with ion chamber sensitive volume as the target was generated and delivered. After MVCT to KVCT auto registration, dosimetric profiles in three directions were measured by stepping the couch away from the registered position. If the registration was perfect, the dose profile peak position should correspond to the registered position. The distance from the maximum dose to the registered location provides the ultimate accuracy of the system, including MVCT imaging accuracy and radiation dose delivery accuracy. **Results:** The average localization differences between the MVCT and KVCT were 0.92mm in lateral, 0.82mm in longitudinal and 0.60mm in vertical directions. Dosimetric measurements showed 1.3mm offset laterally and 0mm offset in the other two directions. The relative large setup error in the lateral direction is partially due to the manual couch adjustment with mechanical scale in that direction. **Conclusions:** The MVCT image fusion can be used to setup SRS patients within accuracy comparable to the current SRS standard.

TU-E-224A-04
Determination of Total Scatter Factors for Stereotactic Radiation Fields by Optimized Fitting of Readings From a Small Ion Chamber and a Mini-Diode

W Du*, F Lerma, N Sakthi, R George, M Schaefer, C Bartee, S Benedict, Virginia Commonwealth University, Richmond, VA

Purpose: To determine the total scatter factors (TSF) for small radiation fields on the BrainLab micro-MLC (M3) and cones by fitting the readings from two detectors: a small ion chamber and a mini-diode. **Method and Materials:** Outputs were measured for 6MV beams using a small ion chamber (Wellhofer IC3, active volume 28mm^3) and a stereotactic diode (Scanditronix DEB050, active volume 0.017mm^3). It has been reported that ion chambers (IC) underestimate output for small fields (<20 mm) and diodes overestimate output for large fields (>50mm). Herein outputs at intermediate field sizes (20-50 mm) were used to combine data from the two detectors. The output from IC was normalized to a reference 10x10cm field; the output from diode was scaled to match the output from IC at intermediate field sizes. The scaling was determined with modified least square optimization. The final TSF was composed of scaled diode output for small fields, IC output for large fields, and their averages for intermediate fields. **Results:** For square fields formed by M3 and secondary jaws, the scaled TSF from diode matched the TSF from IC to within ±0.6% for field sizes 24-60 mm. The diode overestimated TSF of the reference field by 3.2% at depth of 5cm. The IC underestimated TSF by 23%, 5%, 1.4% for 6, 12, 18 mm fields, respectively. Similar results were found for the cones. TSF from diode was 0.702 for the 5mm cone, an improvement of 29% from IC measurement. **Conclusion:** We have demonstrated that neither IC or diode alone provides accurate TSF for stereotactic fields of all sizes. The diode is more accurate than IC for fields <20 mm, however, we show that the diode should be cross-compared with an IC using radiation fields of intermediate sizes. A modified least square optimization method is presented for this purpose.

TU-E-224A-05

Intermediate Energy X-Ray Photons (0.2 - 1.0 MeV) for Radiosurgery: Producing a Beam and Measurement of Radiological Penumbra

B Keller*, L O'Malley, D Beachey, J Presutti, JP Pignol, Sunnybrook and Women's College Health Science Centre, Toronto, Ontario, Canada

Purpose: The main advantage of stereotactic radiosurgery is the steep dose gradient associated with the intracranial dose distribution. We are examining the effects of x-ray energy on penumbra and dose gradient. Specifically, we are exploring the reduction in radiological penumbra for intermediate energy x-ray photons (0.2-1.0 MeV) or so called IEP's. The purpose of this work is two-fold: 1.) to produce an IEP beam using a medical linear accelerator and 2.) to examine the radiological penumbra associated with this beam. **Method and Materials:** A Siemens medical linear accelerator was adapted to produce IEP's. PDD measurements versus depth (SSD=100cm,FS=2x2cm^2) were done in solid water using a Markus parallel plate ionization chamber (PTW Freiburg). These were compared with Monte Carlo computer simulations (MCNP-4C). Monte Carlo involved generating x-ray spectra that impinged upon a SW phantom. A penumbra measurement device (consisting of a half-beam block) was constructed to examine radiation beam edge profiles using film (Gafchromic EBT) at SSD=100cm,FS=1.1cm^2 and depth=2cm. In a separate experiment, film irradiations were done collimating a 3x3mm^2 beam using a 10cm thick brass block flush with the SW surface. In all cases, the geometric penumbra (due to the finite source size) was made negligible by having the collimation very close to the phantom. A high-resolution digital microscope (Axiomat) was used to acquire film profiles. **Results**: *Measured PDD values were 55.4%(surface), 62.6%(5cm), and 34.7%(10cm). Monte Carlo PDD's compared with measurement suggest a nominal 800kV x-ray beam. For the half-beam block, the 80%-20% film edge profiles were 0.345mm (IEP) and 2.10mm (6MV). For the 3x3mm^2 field, there was a 5-fold reduction in radiological penumbra (IEP vs. 6MV).* **Conclusions:** A novel intermediate energy photon beam (of nominal energy 800kV) has been produced using a conventional linear accelerator. There is a substantial reduction in radiological penumbra when using IEP's with small fields.

TU-E-224A-06

Frameless Radiosurgery Using Stereoscopic X-Ray Guidance: System Characteristics and 2 Year Clinical Experience

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Purpose: To evaluate targeting capabilities of a system for image guided "frameless" stereotactic irradiation**. Method and Materials:** System accuracy was investigated using an anthropomorphic head phantom into which a "hidden target" (radio-opaque sphere) was inserted**.** The target was identified on planning CT images and the phantom was fixed to the treatment couch**.** To align the target to isocenter, stereoscopic kV x-rays were fused to planning DRRs**.** AP and lateral verification films were exposed using a 10 mm circular collimator, and the offset of the sphere within the radiation field was recorded**.** The entire process was repeated 50 times in order to achieve an accurate assessment of positioning capabilities. Retrospective data was evaluated from patients having undergone nearly 600 x-ray guided single and multi-fraction stereotactic irradiation procedures**.** From this data the following were investigated**:** the nature and magnitude of systematic and random positioning errors present in conventional procedures, confidence limits on the reproducibility of the mask immobilization device used for multi-fraction treatments, and the potential for replacing rigid head fixation with image guided positioning**. Results:** In phantom studies, a vector displacement of σ = 0.39 mm relative to the "perfect" isocenter was observed**.** Based on a sample population of 50, this provides assurance of accuracy at the 95% confidence level.
Improvement in positioning accuracy was observed in multi-fraction procedures; analysis of 565 fractions showed a mean vector deviation σ = 2.65 mm relative to traditional methods**.** The largest component of this discrepancy was in the superior/inferior direction**.** In comparison, a mean vector deviation σ = 1.62 mm was observed in patients for whom rigid fixation was used**. Conclusions:** Stereoscopic x-ray imaging is an accurate positioning method for cranial stereotactic irradiation**.** The system is as accurate as rigid frame-based methods and can improve the reproducibility of fractionated delivery**.**

TU-E-224A-07

Evaluation of Dose Calculation of SRT/IMRT for Small Lung Lesions Using Monte Carlo Simulations

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Purpose: To assess the heterogeneity effect on stereotactic radiotherapy (SRT) of small lung lesions using Monte Carlo (MC) simulations and to evaluate the accuracy of dose calculation in a commercial treatment planning system (TPS) (Radionics, XKnifeRT) for SRT planning**. Method and Materials:** Five patients were randomly selected for this study**.** For these patients, the sizes of the planning treatment volume (PTV) ranged from 4.2 and 36 cc, and the average densities of the GTV and the ipsilateral lung ranged from 0.659 to 0.93 g/cm3 and from 0.244 to 0.358 g/cm^3, respectively**.** The SRT treatment plans (9 photon beams) for these patients were first generated by the TPS and then recalculated by a MC dose calculation system with the same beam configuration and beam weights as in the TPS**.** Comparisons between the MC and the TPS calculations were made to assess the differences in isodose distributions, median dose (D_{50}), maximum dose (defined as D_1) and minimum dose (defined as D_{99})**. Results:** Dose indices of D_1, D_{50} and D_{99} calculated by the TPS for all patients are found to be significantly larger than those of the MC calculations for the PTV**.** The degree of dose overestimation by the TPS increases with decreasing target volume and target and ipsilateral lung densities**.** Specifically, for PTV volume sizes from 36 to 4.2 cc, the dose calculated from the TPS in D_1, D_{50}, and D_{99} are overestimated by up to 24.7 %, 32.3%, and 38.9% respectively**. Conclusions:** Although the TPS can produce accurate (3%/3mm) treatment plans for homogeneous geometry and for large target volumes in the lung, for small lung lesions the dose calculated by the TPS can be significantly overestimated due to inaccurate heterogeneity corrections**.**

Therapy Scientific Session — Valencia B

IMRT Delivery and Applications

TU-E-ValB-01

Helical Tomotherapy Targeting Total Bone Marrow – Initial Clinical Experience at the University of Minnesota

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Purpose: We report here the successful use of Tomotherapy at delivering intensity modulated radiotherapy to the bone and bone marrow spaces along the entire axis of a patient and describe a dosimetric analysis of the total marrow irradiation (TMI) treatment**.** This is part of a dose escalation trial to determine the maximum tolerated dose (MTD) of TMI when given prior to an alkylator-intensive conditioning regimen for the treatment of high risk or relapsed solid tumors**. Method and Materials:** A patient enrolled in a dose escalation study trial received 600 cGy in 3 fractions**.** Two independent CT image sets (upper and lower part of the body) were obtained**.** A helical tomotherapy treatment plan was created from this CT image sets**.** The quality assurance was evaluated with the use of (a) ion chamber and (b) extended dose range film**.** The isorad-p cylindrical diodes were used for *in-vivo* dosimetry**. Results:** The patient showed neutrophil engraftment on day 11 and platelet engraftment by day 58**.** He is currently well at 120 days post transplant with no evidence of disease**.** The patient developed nausea and vomiting after the first fraction of Tomotherapy TMI**.** Other than above there were no adverse effects of TMI**.** The planned radiation conformed to all bone marrow sites**.** Average doses to lungs, kidneys, heart, and eyes were 50-70% of the prescribed dose for TMI treatments**.** The dose delivery verifications (pretreatment and *in vivo* dose measurement) were within ±3-5% of the expected dose calculated from the treatment planning station**. Conclusions:** We show that helical tomotherapy targeting the bone marrow of the whole body is clinically feasible**.** The clinical implementation of intensity modulated radiation to conform the radiation dose to all active bone marrow of the whole body opened up the possibility of a dose escalation study for high risk patients.

TU-E-ValB-02

Using Magnetically Collimated Electrons and Narrow Intensity Modulated Tangential Photons for Accelerated Partial Breast Irradiation

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Purpose: Previous studies have shown that enface magnetic collimation lowers entrance dose and reduces lateral scattering for electron beams. However, dose uniformity is limited at depth for single beam delivery. This study investigates whether adding narrow intensity modulated tangential photon beams would solve the problem and create a new technique for accelerated partial breast irradiation. **Method and Materials:** Magnetically collimated electron beams were measured and modeled empirically for treatment planning and combined with photon beams on a commercial treatment planning system (Pinnacle 7.6, Philips Medical System). Treatment plans were generated for conformal irradiation of the partial breast using a pair of intensity modulated tangential photon beams plus enface magnetically collimated electron beams. The photon beams were planned via inverse planning with the beam weights of the electron beam adjusted simultaneously. The first MLC segment of the photon beams was fixed to cover the entire planning target volume in the beam's eye view to minimize the effect of target motion. Final treatment plans were analyzed for dose uniformity, for the conformity of the target volume and also for the dose to normal tissues including the skin. **Results:** The combined beam approach significantly improved dose conformity, e.g., narrower separation between peripheral isodose lines, as compared with using either electron beams or a pair of tangential fields alone. The use of enface electron beams significantly improved the target dose uniformity to better than 10%. Due to magnetic collimation, the skin dose was on average lowered by 18% over the use of conventional electron beam for the technique. **Conclusion:** Intensity modulated tangential photon beams combined with magnetically collimated electron beams offers a new technique for accelerated partial breast irradiation.

TU-E-ValB-03

Simultaneous Integrated Boost Utilizing IMRT for the Treatment of Breast Cancer

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Introduction: We compare the dosimetric characteristics of simultaneous integrated boost (SIB) technique utilizing IMRT vs. conventional treatment consisting of medial and lateral tangents followed by an electron boost. **Materials and Methods:** To date, 5 women at our institution have been enrolled and treated using IMRT with SIB. Patients were treated using 25 fractions of 1.8 Gy to the whole breast (45Gy) while concurrently receiving 25 fractions of 2.4 Gy to tumor bed (60Gy). Conventional treatments were planned using the standard fractionation of 1.8 Gy x 25 fractions to the whole breast followed by 2 Gy x 8 fractions to the tumor bed.

The patient data was used to compile population dose volume histograms (pDVH), based on the mean values and include error bars which represent the 1σ uncertainty of the mean. **Results:** The mean percent of the BoostPTV volume receiving 60Gy, was slightly higher for the conventional technique compared to SIB (Conventional = 98±1.4%, SIB=95.0±1.0%). The mean volume of the treated breast outside the BoostPTV, PTV45-Boost, that received greater than 120% of the prescribed dose was more in the Conventional technique then SIB (Conventional=15.9±3.4%, SIB=6.1±1.6%). The mean volume of lung receiving 20Gy was equivalent in both techniques (Conventional=19.8±5.8%, SIB=17.1±5.2%). The mean ipsilateral lung dose was equivalent between techniques (Conventional=10.7±2.2 Gy, SIB=11.9±4.2 Gy). The mean dose to contralateral breast was systematically higher in SIB technique compared to the conventional technique (Conventional=69±39 Gy, SIB=191±126 Gy). The mean volume of the heart that received greater then 30Gy was small for both plans (Conventional=2.8% and SIB=0.4%). **Conclusion:** IMRT with SIB is feasible and allows patients to complete EBRT in about 20% less time than the standard treatment course. It offers improved dose homogeneity to treated breast, comparable normal tissue sparing, and excellent short term cosmesis.

TU-E-ValB-04

Impact On Nodal Dose Distribution From Daily Fiducial Tracking for IMRT Prostate and Pelvic Node Treatments

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Purpose: In prostate only treatments, fiducial seeds can be implanted in the prostate and used for accurate daily targeting of the prostate. For high-risk disease, the regional nodes are simultaneously treated with the prostate using intensity-modulated radiotherapy thereby sparing the rectum, bladder, bowel, and femoral heads. However, the implanted fiducials do not indicate the position of the nodes as the nodes are anchored to the patient's bony anatomy. **Method and Materials:** We measured the displacement of the fiducials with respect to the bony anatomy for each treatment fraction as a surrogate for the displacement of the nodes with respect to the prostate from their original planning position. The displacements, taken from the clinical cases were measured to the nearest 0.01 cm, in LR, AP, and SI directions and were used to perform a forward calculation of the IMRT plan that the patient received during treatment. The dose coverage to the nodes, femoral heads and bowel were evaluated using isodose curves and dose volume histograms. **Results:** Our results indicate for an average patient, the maximum shifts of the seeds with respect to the original DRR position was 0.78 cm inferior, 0.28 cm left, and 0.46 cm posterior. A weighted average of the same directions would be: 0.46 cm, 0.05 cm and 0.13 cm. Forward planning using the weighted average shifts, shows changes in the nodal maximum dose of -0.6% and mean dose -0.2%. The maximum bowel dose changed by -0.5% and the mean dose by -1%. The dose to the left and right femoral heads increased by +2% and +1.2%, respectively. **Conclusion:** The results indicate that for an average patient the difference in the dose planned to the nodal targets and the organs-at-risk are not clinically significant to those received during treatment using fiducial tracking of the prostate.

TU-E-ValB-05

Two Isocenter IMRT with Controlled Junction Dose for Long Volume Sarcomas

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Purpose: Long volume sarcomas are usually treated with a two-isocenter technique. Due to the sharp dose gradients at the field edges, 3 mm setup uncertainties can cause up to 30% dose variations in the overlap region, potentially increasing dose to the bone and risking subsequent fracture. This dose variation is conventionally reduced by using junction shifts. We have developed a two-isocenter IMRT technique to spare bone and simultaneously control the junction dose. The technique uses extended dose gradients throughout a junction region to improve the tolerance to setup uncertainties and inverse planning to develop complimentary dose gradients. **Methods:** An initial dose gradient across a 4-6 cm junction region is induced either with segmented inferior parallel-opposed beams or using variable dose target junction volumes. Superior IMRT fields, which overlap the junction region, are put and optimize doses superiorly and establish a complementary dose gradient to the initial gradient. Then, segments beams are removed and replaced by inferior isocenter fields to complete dose coverage in the junction region and inferior target. **Results:** Four lower extremity sarcoma cases have been planned with this technique in Pinnacle 7.6c, demonstrating the following advantages over the conventional technique: **Improvement in junction dose uniformity:** ±5% target dose heterogeneity for the segments-induced method and ±3% for the variable-dose-volumes method vs. 7% for the conventional moving junction techniques; **Improvement in potential error control:** for 3 mm setup uncertainties, a): ±5% junction target dose shifts vs. up to ±10% hot or cold spots in the conventional treatment; b): Maintained bone sparing dose in junction vs. risk of increased bone dose.**Conclusion:** A technique has been developed to permit the application of IMRT to long limb sarcomas with both critical structure sparing and stable junctioning. This technique has applications to other sites where abutting fields offer treatment or efficiency advantages.

TU-E-ValB-06

Direct Aperture Optimization Based Step-And-Shoot IMRT with Respiratory Gating

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Purpose: Validation of respiration gated IMRT on Siemens linear accelerator has not been reported. This work investigates the reliability, accuracy and efficiency of the delivery of respiratory gated IMRT on a Siemens accelerator. **Method and Materials:** A Siemens Primus accelerator was interfaced with a pressure sensor belt (Anzai Gating system) to deliver step-and-shoot IMRT. A series of IMRT fields, including actual patient, as well as custom segmented fields including the "Picket Fence" were delivered with and without gating (interruption) using a variety of different gating parameters (e.g., duty cycle). Radiographic films and 2D diode array (MapCheck , Sun Nuclear) were used to measure dose distributions. The dose distributions measured with and without gating were compared to identify any delivery error from gating. IMRT with multiple beam angles was also delivered, with and without gating, on a cubic motion phantom. Special measurements were made to individually evaluate dark current, small MU non-linearity and flatness degradation and their cumulative effects on multiple times interrupted fields. Delivery times for MLC and compensator IMRT plans with various segmentations for sample lung and breast cases were compared. **Results:** Beam characteristics for the Siemens accelerator was not altered by gating and gated IMRT with Siemens/Anzai systems was found to be accurate and reliable. Measured dose distributions agreed with the calculated results and/or with those delivered without gating. Picket fence results with and without beam gating indicated same MLC positioning accuracy during the gating. The delivery times for the DAO-based IMRT plans that had small numbers of segments were shorter than those for any other types of IMRT plans including compensators and were comparable with those for 3DCRT. **Conclusion:** The delivery of gated-IMRT with Siemens/Anzai systems is reliable and accurate. The DAO-based IMRT is preferred for gated delivery in terms of treatment times.

TU-E-ValB-07

A Segmentation and Leaf Sequencing Algorithm for IMAT

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Purpose: To develop an intensity segmentation and leaf sequencing algorithm specifically for intensity-modulated arc therapy (IMAT), which can be applied to optimized intensity patterns derived from existing commercial IMRT inverse planning software. Methods and Materials: Three phantom cases, as well as a clinical case were planned using a Hi-Art II (Tomotherapy Inc, WI.) planning station. The end of planning sinograms were then extracted and inputted into our IMAT conversion algorithm. The number of required arcs, deliverable MLC segments for each arc and the relative intensity weighting of each arc were outputted. The number of arcs (modulation) could be controlled by a user parameter, α. The resulting MLC segments were then fed into a fast monte-carlo dose calculation algorithm, NXEGS (NumeriX, LLC) to obtain 3D dose distributions. Dose statistics (max, min, mean) and dose volume histograms of relevant structures were calculated and compared against the results generated by the Hi-Art II system. **Results:** Each plan was converted in under three minutes on a typical desktop PC, with the arc numbers varying between 4 and 15 360° arcs. Qualitatively, the dose distributions obtained from the IMAT plans were similar to the tomotherapy results, as well as planned doses. Quantitatively, the IMAT plans were slightly degraded, with the average dose to normal structures being 7.5% higher for IMAT vs. tomotherapy. However, the IMAT plans generally met planned values, being 9.1% below for maximum doses to normal structures. The number of arcs and therefore the resulting dose distribution could be varied according to α. **Conclusions:** IMAT segmentation and leaf sequencing produced deliverable IMAT MLC segments and relative arc weights directly from Hi-Art II optimized plans. The algorithm was computationally efficient, and produced similar dose distributions. Additional optimization could improve resulting dose distributions further. IMAT back-up for tomotherapy is another potential application.

Workshop — Room 230 C

Digital Radiography QC Workshop: Part II - Hands On Demonstrations

TU-E-230C-01

Digital Radiography QC Workshop I and II

L Goldman*, Hartford Hospital, Hartford, CT

Computed radiography and digital radiography systems now comprise a large segment of radiography work. It is important that appropriate performance testing and quality control (QC) tools and procedures be made available for these systems. The vendors and/or manufacturers of digital imaging systems may provide–or make available–test tools, software and procedures for performance evaluation and routine quality control testing of their digital systems. Currently, such tools and programs vary significantly from manufacturer to manufacturer.

This two-part workshop will include both formal presentations and hands-on demonstrations. During the first half of the workshop, each participating vendor or manufacturer will present a brief (12-15 minute) overview of tools and procedures for performance testing and QC of their systems. The second half of the workshop is dedicated to hands-on demonstrations at table-top exhibits hosted by each participating vendor. Exhibits will include test tools, workstations and samples of performance testing and QC test procedures.

Companies participating in this workshop will include Agfa, Fuji, General Electric, Kodak, Konica, IDC, LoDox, Philips and potentially others.

Educational Objectives:

1. To understand performance test procedures used by various DR/CR systems
2. To see types QC test tools and procedures made available with DR/CR systems
3. To obtain hands-on demonstration of DR/CR ttesting and QC procedures

Exhibit Hall F

Therapy
Moderated Poster Session

Moderated Poster - Area 1 (Therapy): Dosimetry Instrumentation and Clinical Measurements

TU-FF-A1-01

Characterization of EBT Versus MD55 Gafchromic® Films for Relative Dosimetry Measurements

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Purpose: To evaluate the EBT® radio-chromic film for relative dosimetry in comparison to MD55®. **Method and Materials:** For dose-response study, EBT and MD55 films were irradiated to dose ranges 0-15 and 0-40 Gy respectively. Photon beam energies of 6 and 18 MV were used to study energy dependence. Films were scanned using a scanner from Micro-densitometer Photoelectron Corporation. The scanner uses a CCD camera. The two diffused-light beds using light-emitting diodes, operating at 636 and 665 nm, were used for EBT and MD55 films respectively. For flat-field subtraction at start of a scanning session, in case of EBT, an un-irradiated film was scanned employing a black mask covering the light box's area outside the film. In case of MD55, un-masked light box without a film was scanned for the flat field subtraction. For fading study, films were read over a period 2-20 days after irradiation. For light sensitivity, un-irradiated films were exposed to florescent light to 6 hour maximum. **Results:** Unlike MD55, light sensitivity of EBT is found to decrease with pre-irradiation level. With 2Gy pre-irradiation, it is comparable to MD55. Fading of EBT is comparable to MD55. The small energy dependence observed beyond 8Gy for EBT is considered negligible. Percent uncertainty in relative-dose determination from two OD values is obviously expected to increase with separation between the OD values, and to be higher at lower OD levels. It is comparable for both films, and is typically

estimated to be 0.8% for determination of 50% of 2Gy. **Conclusions:** Dosimetry characteristics of EBT are comparable to MD55. Its higher sensitivity to radiation and availability in larger size makes it preferable as a relative dosimeter for RPC use.
Work supported by PHS grant CA10953 and CA81647 awarded by NCI.

TU-FF-A1-02

Estimating Dose to ICD Outside the Treatment Fields Using Skin QED Diode

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Purpose: To determine calibration factors for several diodes and TLD as a function of distance from the field edge. These can then be applied to measure dose at any out-of-field point. **Method and Materials:** Skin QED Diode has been used to estimate the radiation dose to patient's ICD outside the treatment fields. The ICDs from three major manufacturers have an outer case made of Titanium (Ti) ranging from 0.4- 0.6 mm thickness. With the correction of mass attenuation coefficients of Ti and tissue at 6-MeV, it is estimated that 0.5- mm Ti is equivalent to 2.4-mm tissue. The manufacturers recommend that the ICD be implanted subcutaneously underneath skin at 3-4 mm depth. Therefore, a 5-mm bolus with skin diode 1-mm inherent buildup is close to the true depth of the electronic device. The responses of the skin diode with and without bolus, an ISORAD photon diode, and TLD were measured per unit dose to water at off-axis distances up to 10-cm from the field edge. Dose at each point was measured by an ionization chamber located at 0.5-cm and 1.5-cm depth. **Results:** The calibration factor as a function of distance from the field edge, relative to its central axis value, changed very little for TLD and for the QED skin diode with 0.5-cm bolus; decreased by a factor as large as 2 for the photon diode; increased by a factor as large as 3.4 for the QED diode without bolus. **Conclusions**: The use of diodes for out-of-field dose measurements requires knowing the calibration factor as a function of off-axis distance. This can be readily done at each institution or the manufacturer can provide the pertinent relative response data. The skin QED diode is easy to use as an in-vivo dosimeter, and, with 5-mm bolus, its behavior is similar to TLD.

TU-FF-A1-03

Comparison of Surface Dose Resulting From SMLC and Compensator-Based IMRT for Breast Radiotherapy

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Purpose: To compare the surface dose to the ipsilateral breast between compensator and MLC-based IMRT for breast radiotherapy both with and without simulated respiratory motion. **Methods & Materials:** An anthropomorphic polystyrene breast phantom mounted on a moving platform was used to simulate the human breast and its respiration-induced motion during radiotherapy. MOSFET dosimeters were placed on the surface of the phantom at 5 approximately uniformly spaced positions in the central axial plane. Two common IMRT treatment techniques were then used to deliver a uniform dose of 1.8 Gy to the simulated breast both with and without simulated respiratory motion with 1 cm amplitude and a period of 4 seconds. Both techniques used the same parallel-opposed half-beam-blocked tangential beams, but one used bismuth polyethylene compensators to create the modulation while the other used the segmental MLC (SMLC) delivery technique to create the modulation. The segment shapes and weights for the SMLC delivery were created from the fringe lines of the compensator maps so that the plans delivered essentially identical dose distributions to the phantom beyond the build-up region. **Results:** Respiratory motion did not significantly alter the surface dose for either technique. All five dosimeters measured lower surface doses from the SMLC plans in comparison to the compensator plans. The average surface dose for SMLC delivery of 127 cGy was 6% lower than the average dose of 135 cGy measured for compensator delivery. **Conclusion:** The secondary and scattered radiation produced in the compensator increases surface dose. The use of SMLC IMRT results in lower dose to the skin than that from compensator-based IMRT and this fact should be considered when planning breast IMRT cases.

TU-FF-A1-04

Illustrating Manufacturing Variability in Prostate Brachytherapy Seeds Through X-Ray Spectrometry and Radiochromic Film Measurements

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Purpose: To illustrate the effects of manufacturing variability on ionization chamber measurements of a batch of "identical" prostate brachytherapy seeds in terms of emergent spectrum, in-air anisotropy, and internal distribution of radioactive material. **Method and Materials:** A batch of six "identical" prostate brachytherapy seeds were calibrated in terms of air-kerma strength using the Wide-Angle Free-Air Chamber (WAFAC) at the National Institute of Standards and Technology (NIST). The seeds were subsequently characterized using a variety of experimental techniques including well-ionization chamber response, x-ray spectrometry, and radiochromic-film contact-exposure measurements. In-air anisotropy was quantified by the air-anisotropy ratio, α_S, calculated from x-ray spectrometry measurements performed with the seed rotated at 90-degree intervals about an axis perpendicular to the mid-point of the long axis of the seed. **Results:** Variations in the internal distribution of radioactivity among the six seeds were observed in optical density profiles through the long axes of the seeds, as measured by radiochromic film. X-ray emergent spectra showed differences in the admixture of silver fluorescence x-rays between seeds, which modified the average energy of the spectra and thus the relative response of the well chamber and the WAFAC. Variations in α_S affected relative ionization chamber response due to the difference in measurement geometry solid angle between the WAFAC (cone of 8 degree half-angle) and the well chamber (approximately 4π). **Conclusions:** The effects of variations in emergent spectra and anisotropy were small enough such that the well-chamber-to-WAFAC response ratio for all but one of the seeds was within the 1.00 % tolerance criterion as recommended by the Calibration Laboratory Accreditation Subcommittee of the AAPM. The "out-of-tolerance" seed was shown to have an admixture of silver fluorescence x-rays in the emergent spectrum significantly different than that of previously calibrated seeds of the same design.

TU-FF-A1-05

A Motion Phantom Study On Helical Tomotherapy: The Dosimetric Impacts of Delivery Technique and Motion

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Purpose: To determine the optimal delivery technique for treating moving targets with Helical Tomotherapy (HT) we measured the dosimetric effects of various motion and Tomotherapy plan parameters using a lung motion phantom. **Method and Materials:** A motion phantom system was constructed using a programmable motor driving a moving platform. Tomotherapy plans were delivered to a phantom which mimicked lung heterogeneity by using wood inserts with the density of lung tissue and a 3.3cm spherical tissue density material as tumor. A cylindrical planning target volume (PTV) was used with a length and diameter of 3.3cm including the sphere. Treatment plans were created using jaw sizes of 1.04 and 2.47cm with incremental gantry rotation times ranging from (10s) to (60s). Treatments based on these plans were delivered to the phantom with motion periods of 3 and 5 seconds, and amplitudes of +/-6 and 10mm. All plans were normalized to 2.0 Gy fractional doses to 95% of the PTV and Kodak EDR-2 film was used for 2-D dose measurements. Axial dose profiles and cumulative dose volume histograms (DVH) of plans for moving and static phantom conditions were compared. **Results:** Target edge under-dosing is less with a jaw size of 2.47cm than 1.04cm in this experimental system. Shorter motion periods (3s) and greater gantry rotation (>5 times motion period) resulted in better PTV coverage referenced to static phantoms. Greater than 90% of the PTV received the prescription dose even when the phantom moves +/-10mm. When the gantry rotation time to motion period ratio approached 3 PTV coverage was compromised. **Conclusions:** PTV expansions smaller than motion excursion may be possible for lung tumor treatment by HT. Larger jaw width provides better target coverage because of the wider inferior/superior penumbra. Increasing the ratio of the gantry rotation time to the motion period improves target edge coverage.

TU-FF-A1-06

A Robust Scalable Parallel Processing System for Radiation Therapy

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Purpose: To develop a robust Linux—based cluster for the parallel computation of problems of interest in a radiation therapy environment. This system should be robust, scalable and easy to manage. It should be constructed from commercially available low cost hardware and use only open source software tools to manage the system. **Method and Materials:** This cluster was constructed using a distributed memory model with the Message Passing Interface (MPI) protocol. The use of distributed memory requires a fast backbone to efficiently distribute programs and data to the various cluster nodes. This rapid data transfer was accomplished using a Gigabit Ethernet switch which allows a peak transfer rate of 100 Mbytes/sec. The cluster currently consists of 76 CPU's each with a minimum of 512 Mbytes of RAM. The individual nodes run an open source version (Centos 4.0) of the Redhat Enterprise 4.0 Linux operating system. The MPI protocol is implemented using the open source implementation, MPICH. Cluster node management is accomplished using the ROCKS 4.0 shareware toolset. The compilers and debuggers (C++ and FORTRAN for Linux) are Intel 9.0. Finally, the Integrated Development Environment (IDE) is the Eclipse open-source project v3.0.1 with PHOTRAN extensions. **Results:** This cluster has recently been commissioned and several benchmark tests have been completed. Factors of 15X – 60X improvement in speed for parallelizable sections of various codes have been demonstrated. **Conclusions:** This system is robust enough to solve complex problems which were intractable with our previous computational tools. The demonstrated speed improvements will allow for the implementation of codes for problems such as: real-time dose calculation, fast IMRT optimization, and the convolution of correlated CT datasets to account for patient motion.

Exhibit Hall F

Therapy Moderated Poster Session

Moderated Poster - Area 2 (Therapy): Teletherapy Planning and Delivery II

TU-FF-A2-01

Feasibility of Cone-Beam CT Based Treatment Planning

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Purpose: To investigate the feasibility of cone-beam computed tomography (CBCT)-based treatment planning. **Methods:** HU of material disks in Catphan, HU profiles for homogeneous and inhomogeneous phantoms, and HU values in different tissue areas of brain, thorax and prostate patients were compared in CBCT and CT images. Plans with one beam based on CBCT and CT of phantoms and patients were compared using MU/cGy values and isodose distributions. For patient cases, 3D plans and IMRT plans based on CT images were generated, and then verification plans based on CBCT were generated. The isodose distributions and dose values at the isocenter were compared between two plans. **Results:** HU values of CBCT are very close to those of CT in Catphan. However, HU profiles of homogeneous and inhomogeneous phantoms in CBCT show inhomogeneous distribution compared to those in CT with large scatter. Large scatter contribution becomes greater in patient cases. The lung or fatty tissue appears with even lower HU values in CBCT than in CT. Resulting MU/cGy differences are generally within 2%, but a beam passing through a significant amount of the lung or bone shows 2 – 3% of MU/cGy difference. The isodose distributions of CBCT-based verification plans and CT-based plans for brain and prostate patients are very similar with the dose values less than 2% different. The dose value is about 4% higher in CBCT-based verification plan than in CT-based plan for the thorax patient and the isodose distributions in the high dose area inside of the lung shows disagreement between the two plans. **Conclusion:** This study validates CBCT-based treatment planning by comparing with the gold standard CT-based treatment planning. CBCT-based plans could be used for most cases. However, beams should be selected with a consideration to avoid a large part of lung.

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TU-FF-A2-02

Extended Range CT-Value Analysis in Megavoltage CT Imaging and Therapy

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Purpose: To investigate uses of megavoltage CT (MVCT) scans for high-Z materials, such as prosthetics, and Fletcher-Suit applicators. The image quality of kilovoltage CT (kVCT) scans is not clinically useful due to substantial artifacts. We investigated the relationship between MVCT derived "Hounsfield" units (HU) and electron density. Knowing this, we used MVCT scans to the treatment planning process. Then we evaluated the expected dose represented on the plan to actual measured dose taking MVCT derived inhomogeneities into account. **Method and Materials:** A Siemens 120 kVp CT scanner and 3.5 MeV Tomotherapy unit were used to scan a "Cheese" phantom containing 16 plugs whose relative electron density varied from 0.292 to 8.086. The 3-4 mm slice thickness images were transferred to Eclipse planning station to obtain mean HU. Tomotherapy treatment plans with field width of 2.5 cm, pitch 0.25, and modulation factor 2.5, were completed utilizing extended range HU-density tables and designed to deliver 2 Gy per fraction to a planning target volume (PTV). An A1SL ion chamber was used for absolute dose measurement, while EDR2 film for evaluation of dose profiles. **Results:** High-energy MVCT images compared to the kVCT showed much-reduced artifact. For unit density and low-Z materials (tissue equivalent), delivered dose was within 1% of kVCT-image based plans and within 1.6% of MVCT based plans. kVCT images could not be used for extracting HU in high-Z material due to saturation in CT numbers. For high-Z materials, HU were extracted from the MVCT image set. MVCT-based plans were within 0.6%-5.3% of the target dose depending on the high-Z material orientation and location compared to the PTV. **Conclusion:** We show that MVCT-based treatment plans containing high-Z material can be done accurately. We are exploring clinical applications of this study for patients with prostheses, and intracavitary radiotherapy.

TU-FF-A2-03

Construction and Dosimetry of a Prototype Automated Few-Leaf Electron Collimator (FLEC) for Delivery of Energy-Intensity Modulated Electron Therapy

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Purpose: To design and implement an automated "few leaf electron collimator" (FLEC) used for energy modulated electron therapy (EMET) using Monte Carlo-based treatment planning. This study investigates the optimization of the physical design of the FLEC and provides preliminary validation results of comparison between Monte Carlo calculations and film measurements for complex intensity/energy modulated electron fields using a manual replica of the FLEC. **Methods and Materials:** The FLEC design was guided by Monte Carlo studies to optimize the physical configuration of the collimator leaves within the linear accelerator. To validate our Monte Carlo-based treatment planning system, we used a manual FLEC to acquire output of jaws collimated fields using ionization chamber and compared them with Monte Carlo calculation. Calculated two dimensional dose distributions were compared to film measurements obtained using energy-independent GafChromic® HS films. A gamma-index analysis quantifying the difference between calculation and measurements is discussed. **Results:** A prototype of the automated FLEC was constructed with 1.1 cm thick and 3 cm width copper leafs of. The field collimated by the FLEC is backed up by jaw openings following the FLEC projection that provides an optimum field quality. The compact design of the FLEC, including motors, encoders, switches, and necessary wiring, is suitable to be attached to a clinical electron applicator. Software was developed to facilitate remote control of the FLEC system. A comparison between Monte Carlo calculation and film measurements of complex intensity maps shows agreement within tolerated accuracy measures (3% for 3 mm) based on gamma index analysis. **Conclusions:** The results of this work confirm most of our design objectives and support the potential of using the prototype FLEC for modulated electron therapy delivery. QA procedures for the EMET treatment delivery using the FLEC integrated with the linear accelerator are being investigated.

TU-FF-A2-04

Preliminary Radiological Characterization of An Active Proton Beam Spreading System for Therapeutic Use

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Purpose: At most proton therapy centers, a clinically useable radiation field is delivered by means of a passive beam spreading system. However, at this proton therapy facility, an active proton beam spreading system has been installed in an isocentric gantry treatment room. Because there exists no standard acceptance test guidelines for an active proton beam delivery system, this presentation serves to report methods and preliminary results from the acceptance testing and early commissioning phase. **Method and Materials:** Though passive spreading is the most common method of beam formation, the use of metal scatterers reduces the maximum beam range and results in a higher integral dose from concomitant scattered radiation. The active proton beam delivery methods, such as uniform scanning, have the potential of increased range and lower integral dose in comparison to passive spreading. Ionization chamber scans in a step-by-step mode in a scanning water phantom were used to acquire the bulk of the data. **Results:** In the transverse plane perpendicular to the beam axis, the active beam delivery system is capable of delivering a field to within the clinical specification of +/- 2.5%. In addition, the penumbra from the beam delivery system at 5 and 25 cm depth increase from 1.6mm to 10.0mm along the pristine Bragg peak. Along the longitudinal axis, the radiation field meets the range requirement. The SOBP causes a range deficit with the pristine peak of 0.25mm measured from 80-20% dose levels. Also, the SOBP extent flatness exceeds the clinical specification of +/- 2.5% and adjustable with a skewness parameter on the fly. **Conclusion:** The active beam delivery system at this proton therapy facility is capable of delivering a therapeutically acceptable radiation beam. Furthermore, the active system represents a significant step enroute to the goal of intensity modulated proton therapy.

TU-FF-A2-05

A Laser System and Target Design for Proton Acceleration

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Purpose: The interaction of powerful laser pulses with solid-state targets has recently been demonstrated to produce beams of energetic protons. The generation and characterization of laser accelerated protons is nowadays one of the most rapidly developing fields in accelerator physics. On the application side, the development of a cost-effective and energy efficient way of producing proton beams represents a major breakthrough in hadron therapy. In this work we present a detailed study of the requirements imposed on the laser system in order to achieve extremely high peak intensities, necessary for proton acceleration. Different target designs are experimentally investigated. **Method and Materials:** The laser system consists of a chain of commercial lasers and amplifiers, based on Titanium doped sapphire crystal as active medium, followed by a custom-design power amplifier. The technique of chirped-pulse amplification is employed as the most efficient amplification scheme for ultra-short laser pulses developed to date. Sharp focusing is achieved by an off-axis parabolic mirror designed for low losses and minimal aberrations. Frequency resolved optical gating measurements provide the complete laser pulse characterization. **Results:** After pulse compression in vacuum we achieved 40 fs pulse duration with 1.1 J in each pulse at 10 Hz repetition rate. Focused beam spot size of 8 μm has been accurately measured. We demonstrate capability of obtaining pulses with characteristics suitable for proton acceleration. All stages of the pulse generation, amplification, compression, and conditioning are discussed in detail in this study. Different regimes of acceleration are discussed along with experimental evidence for their realization. **Conclusion:** We present a detailed characterization of the current state of our laser system and a novel target chamber design. The implications for proton acceleration along with optimization strategies for enhanced proton yield and collimation are discussed as well.

TU-FF-A2-06

Dynamic IMRT Treatments of Sinus Region Tumors: Comparison of Monte Carlo Calculations with Treatment Planning System Calculations and Ion Chamber Measurements

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Purpose: To compare Monte Carlo (MC) calculations for dynamic IMRT treatments of tumors in the sinus region with Eclipse treatment planning system dose calculations (pencil beam, modified Batho correction), and ion chamber measurements. **Methods:** The EGS4nrc MC code, BEAMnrc, was commissioned to simulate a Varian 21Ex Linac. The accuracy of the simulation for IMRT plans was evaluated using the RPC head phantom by comparing MC, Eclipse, RPC's TLD results, and ion chamber in solid water phantom measurements. The MC code was then used to simulate dose distributions for 5 patients who were treated using dynamic IMRT for tumors in the sinus region. The results were compared with absolute and relative dose distributions calculated using Eclipse (modified-Batho inhomogeneity correction). Absolute dose differences were also compared ion chamber results. **Results:** Comparison of the doses calculated on the RPC phantom using MC, compared with Eclipse, ion chamber, and TLD measurements showed differences of -3.9%, -1.4%, and -2.0%, respectively (MC is colder). Relative dose distributions for the patient plans calculated using MC agreed well with those calculated using Eclipse with respect to targets and critical organs, indicating the modified-Batho correction is adequate. Average agreement for mean absolute target doses between MC and Eclipse was -2.9±2.2%. Agreement between ion chamber and Eclipse for these patients was –2.2±1.9%, compared with 0.2±2.0% for all head and neck IMRT patients. When Eclipse doses were corrected based on ion chamber results, agreement between MC and Eclipse improved to –0.7±2.0%. **Conclusions:** (1) The effect of inhomogeneities in the sinus region is adequately accounted for by the modified-Batho correction in Eclipse. (2) Both MC and ion chamber results indicate a small systematic uncertainty in the doses calculated using the treatment planning system for this subset of patients.

Exhibit Hall F

Imaging Moderated Poster Session

Moderated Poster - Area 3 (Imaging): Imaging for Therapy Guidance

TU-FF-A3-01

X-Ray and Optical Monte Carlo Study of Thick, Segmented Scintillators for MV Imaging

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Purpose: To study the imaging characteristics of thick, segmented, 2-D $CdWO_4$ crystal-photodiode detectors as a function of crystal height, septa material and optical reflectivity, x-ray beam spectrum and beam divergence using a two-step Monte Carlo approach involving both x-ray photon transport at megavoltage (MV) energies and the optical photon transport in scintillator and photodiodes. **Method and Materials:** We have studied the spatial frequency dependent detective quantum efficiency (DQE) of thick, segmented, 2-D $CdWO_4$ crystals in contact with silicon photodiode arrays. The energy deposited into the 3-D voxels (1 x 1 x 1 mm^3, septa thickness = 0.15 mm, fill factor = 72%) of the detector for each of the 6 and 3.5 MV x-ray photons in a normally incident pencil beam was calculated using the DOSXYZnrc user code of the EGSnrc Monte Carol system. The isotropically emitted optical photons in each voxel were calculated using the average $CdWO_4$ optical yield and transported to the photodiode array using DETECT2000 optical Monte Carlo code. A 10° beam divergence angle was also simulated. The detector DQE was calculated using the spatial distribution of optical photons. **Results:** The DQE increases with the crystal height only if the reflectivity of the septa material is high (0.975). For poor reflectivity (0.65 and 0.8), the increase in the DQE of the taller crystals to MV photons is seriously offset (from 42% to less than 20% for 3 cm tall crystals) by the decreased probability of detecting optical photons. Similarly, the increase in DQE due to the lower energy photons is obtained if the high reflectivity of septa material is maintained for the detector. Beam divergence in thick crystals also reduces the DQE.

Conclusion: High reflectivity of the septa in thick, segmented scintillation detectors is very important to achieve high DQE.

TU-FF-A3-02

Preliminary Investigations Into Combined CT/SPECT Imaging Onboard Therapy Machines

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Purpose: Functional and molecular (F&M) imaging onboard radiation therapy machines would allow for targeting of functional tumor volume, and avoiding of healthy tissue, by guiding and modifying radiation beams, in the treatment room, based on real-time F&M information. This capability might be particularly critical when tumor is located within deformable internal organs. When deformable structures do not present adequate contrast in the CT image, precise localization of tumor and healthy-tissue can be difficult using onboard CT alone. Also, since some F&M properties can change on the time scale of an hour, onboard F&M imaging may be important for its temporal proximity to therapy. Given the benefits of onboard F&M imaging and the essentiality of onboard CT, the purpose of this study is to investigate the feasibility of using flat-panel detectors (FPDs) to accomplish both CT and SPECT onboard therapy machines. **Method and Materials:** A 10 mCi point source of Tc99m was placed 100 cm from a bar phantom, with a FPD immediately behind the phantom. Data were acquired for 10 seconds. A signal-to-noise ratio (SNR) was computed with signal given by difference in mean activities in the exposed and bar-covered regions and noise given by standard deviation of amplitudes in the 0.776-mm-wide exposed-region pixels. **Results:** The bar phantom was clearly visualized. The measured SNR was 4. **Conclusion**: Additional experiments will be required to evaluate FPD SPECT when radiotracer is distributed over an extended source and a collimator is employed. Since FPDs have not been designed for SPECT, only limited SPECT performance can be expected. However, these initial characterizations of FPD SPECT may support FPD design modifications, such as thicker scintillators, that enable combined SPECT/CT imaging using FPDs mounted onto therapy machines.

TU-FF-A3-03

Investigation of Dose Reduction Strategies for Image Guidance with KV-CBCT in Radiation Therapy

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Purpose: To explore methods of minimizing the dose to eye (lens) and contra-lateral breast during image guidance with kilo voltage cone beam CT (kVCBCT) in radiotherapy. **Method and Materials:** A set of high sensitivity MOSFET, with high bias, was utilized for dose measurements. The MOSFET calibration factors, in terms of cGy/mV, were determined by measuring the response at a depth of 2.0 cm in water against ion chamber. Dose to eye was measured using a head phantom for 360-degree full rotation, 270-degree and 195-degree scans (half rotation plus fan angle). The eye dose was also measured for 195-degree scan simulating x-ray tube rotation anterior as well as posterior to the head. Dose to contra-lateral breast was also evaluated with a Rando phantom. The dose measurements were performed for 120kV beams with mAs values of 0.5, 1, 2 and 3.2 per projection. The images obtained during these measurements were analyzed for image quality. **Results:** The dose measured on the surface of the eye was less by 50% for 270-degree scan and by 75% for 195-degree posterior scan compared to 360-degree scan. The dose to contra-lateral breast was less by 30% and 40% for 270 and 195-degree scans. Excellent image quality was obtained with 0.5 mAs/ projection and 320 projections over a complete rotation scan, however, acceptable image quality also resulted with 195-degree scan with 75% reduction in eye dose. Reducing the number of projections, over a given arc angle decreased the dose to critical organ, but resulted in artifacts. **Conclusion:** Reducing the scanning arc resulted in significant reduction in dose without much loss of image quality. A posterior scan reduced the dose to eye considerably without any significant change in the image quality. This work demonstrates that there are opportunities to minimize dose to critical organs without compromising the quality.

TU-FF-A3-04

An In Vivo Comparative Study of the MV and KV Cone Beam Computed Tomography Image Quality of a Lung Patient

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Purpose: To compare image quality, reconstruction artifacts and tumor visibility for kV and MV cone–beam computed tomography (CBCT) scans reconstructed with the same algorithm. **Method and Materials:** A protocol lung-cancer patient was set up in the identical treatment position for kV and MVCBCT using a Varian On-Board Imager CBCT and an in-house MVCBCT imaging system. For both scans the gantry made a 1-minute, 360^o continuous rotation. For the MVCBCT, ~460 projection images were acquired at 6MV for ~13 MU; for kVCBCT ~600 projections were acquired using 125 kVp, 80 mA and 25-ms exposure time per projection, resulting in ~2cGy at isocenter. Reconstruction was performed using the Feldkamp back projection algorithm. Both scans were registered to the treatment plan CT. The visibility of three selected regions (bronchus, vertebrae, heart) is compared using the corresponding signal-to-noise ratio (SNR). The contrast ratio (CR) and contrast-to-noise ratio (CNR) at the tumor are also compared for ease of tumor identification. **Results:** The SNR of bronchus, vertebrae and heart are 25, 34 and 33 respectively for MVCBCT while the corresponding values in kV scan are 17, 33 and 42. For tumor identifiability, CNR and CR are 11 and 2 respectively for MV scan, and 10 and 2 for kV scan. The CNR of the vertebrae in MV and kV cases are 2 and 6. Time to register the kV image is approximately 50% less than MV image. Similar breathing artifacts are present in both scans. **Conclusions:** Both kV and MV scans deliver usable images. The tumor can be discriminated from the lung background. Higher bone contrast in kV scan helps to reduce time required to register the scan with the planning CT. **Conflict of Interest:** Research sponsored by NCI Grant P01-CA59017 and Varian Medical Systems; Research agreement with Varian Medical Systems

TU-FF-A3-05

Dosimetric Effect of Cupping Artefact in MVCBCT Images of the Head and Neck Region

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Purpose: To quantify the dose calculation accuracy achievable with 3D anatomical images obtained by Megavoltage Cone-Beam Computed Tomography (MVCBCT) for the head and neck region (H&N). **Method and Materials:** MVCBCT images of inserts of different density immersed in water were obtained. This allowed the tuning of the parameters used for the image reconstruction. A MVCBCT number versus material density curve was also extracted for dose calculation purposes. MVCBCT images of a Rando phantom head were then acquired on a linac treatment couch with two different gain image calibrations and in two different positions relative to the room isocenter. Voxel-based and band-pass filter cupping artifact reduction methods were applied on all MVCBCT images. Images of the same phantom were also obtained with a kVCT. All images were transferred to a treatment planning system and dose calculations performed with various beam configurations. The dose differences obtained with the kVCT images and the MVCBCT images were analyzed using a gamma index function. **Results:** At best, 96.1% and 98.8% of the dose points calculated with the MVCBCT images were within the dose calculated with the kVCT image by [2%, 2 mm] and [3%, 3 mm], respectively. The worst cases observed had fractions of 87.7% and 96.3% of the dose points that agreed within [2%, 2 mm] and [3%, 3 mm], respectively. The cupping artifact reduction methods tested did not significantly improve the dose calculation for most cases. **Conclusion:** With proper calibration, dose calculations with MVCBCT images in the H&N region are feasible with an accuracy of [3 %, 3 mm] or less. The cupping artifact for H&N imaging does not lead to important dose calculation errors. Dose calculation with patient MVCBCTs and treatment plans are ongoing. **Conflict of Interest:** Research sponsored by Siemens OCS.

TU-FF-A3-06

Dose Calculation in Presence of a Metallic Object Using Megavoltage Cone-Beam CT

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Purpose: CT image artefacts caused by the presence of metallic objects hinder organ delineation and preclude precise dose calculation. In contrast, the presence of high atomic number material has relatively little impact on the image quality of Megavoltage Cone-beam CT (MVCBCT). The objective of this work was to determine if MVCBCT could be used for accurate dose calculation in the presence of metallic objects.

Material: Experiments were performed with a 16cm diameter cylindrical water-equivalent phantom. MVCBCT and kVCT images of the phantom were acquired with and without a 1.5 cm diameter steel rod (3 mm wall thickness) sitting on the phantom. Using a treatment planning system, dose distributions were calculated for a 6 MV 10 cm square field AP beam for these configurations. Dose measurements were performed using an ion chamber placed at isocenter and mosfet detectors placed at 35 locations in the phantom. Measured and calculated dose values were compared. **Results:** Without metal, dose calculated in the phantom using either the kVCT or the MVCBCT image corrected for cupping artefact were all within 2% of each other and of the measured values, showing the ability to use the MVCBCT for dose calculation. In the presence of the metallic object, erroneous density values, around the rod, made dose calculation on the kVCT unreliable. MVCBCT provided correct density values (within 5%) and differences between measured and calculated dose values were on average 3.2% (SD 3.4%). The two largest differences (10.6% and 8.9%) were found in a high dose gradient region below the rod. **Conclusion:** MVCBCT can be used in a treatment planning system for dose calculation in the presence of metallic objects. Results for non-cylindrical geometries will also be presented.

This research is supported by Siemens

Exhibit Hall F

Imaging Moderated Poster Session

Moderated Poster - Area 4 (Imaging): Radiography and Fluoroscopy

TU-FF-A4-01

Instrumentation Noise Equivalent Exposure (INEE) Representation for High Sensitivity X-Ray Imaging Detectors

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Purpose: For modern high-sensitivity digital imaging detectors operating at fluoroscopic exposure rates, the additive instrumentation readout noise may prevent desirable optimal quantum-limited performance. A formalism and experimental validation of the representation of instrumentation noise in terms of the equivalent x-ray entrance exposure to the detector is presented as a more practical noise measure than the equipment-invasive measurement of electrons per pixel. **Method and Materials:** The instrumentation noise in terms of exposure equivalent is added in quadrature to the quantum noise to give the total measurable noise. Experimental validation was done using two different CCD-based detectors: a high-sensitivity microangiographic fluoroscope (MAF) and a less sensitive microangiographic detector (MA). Both detectors have a CsI(Tl) phosphor coupled to a fiber-optic taper followed by a CCD camera (the MAF additionally has a variable-gain light amplifier between the taper and the CCD). To determine the INEE for both detectors, a least-squares regression technique was used to fit the measured data to the theoretical equation relating the signal-to-noise ratio squared (SNR^2) to the detector entrance exposure. **Results:** The SNR^2 versus exposure plot deviates from linear behavior at lower exposures as expected, and closely follows the modeled equation used to derive the INEE. The measured INEE for the high-sensitivity MAF was 0.034 μR and that for the MA was 10.8 μR. **Conclusion:** A formal treatment of the instrumentation noise in terms of the detector entrance exposure was developed and validated by using two different CCD based systems of different sensitivity. This study demonstrates that the INEE is a practical way to gauge the range of quantum-limited performance for clinical x-ray imaging detectors, with the implication that detector performance at exposures below the INEE will be instrumentation-noise limited rather than quantum-noise limited.

(Partial support from NIH Grants R01EB002873, R01NS43924, and Toshiba Medical Systems Corporation)

TU-FF-A4-02

Diagnostic Medical Physics Performance Evaluation of a Portable Digital Flat Detector System

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Purpose: To outline a set of tests to evaluate clinical flat detector performance in terms of image quality, artifact evaluation, detector radiation exposure response and system refresh rate/throughput. **Method and Materials:** The tests were performed on a Canon CXDI-50G detector associated with Siemens Axiom Sireskop SD Radiography/Fluoroscopy (R/F) system. For most tests, all image processing filters were turned off and look up table was selected to get unprocessed image data. Detector Dark noise, uniformity and distortion measurements were performed. Relationship between detector exposure, pixel value and detector exposure index was established using three different exposure levels (0.15, 1.13 & 5.7 mR) and R^2 calculated. Spatial resolution was determined in four quadrants of the detector. Percent contrast was obtained at three exposure levels with 1 mm Copper filtration. The detector was evaluated for possible ghosting related artifacts between exposures. Detector exposure index (EXI) reproducibility was tested. Refresh rate was measured for the flat detector while used in table top, table bucky and wall bucky mode using all clinical organ program settings. **Results:** Dark noise EXI was 0 with a pixel value of 0.5. Maximum non uniformity relative to global average was 4.4%. Relationship between detectors exposure, pixel value and exposure index was linear with R^2 of 0.9999 and 1 respectively. Spatial resolution was approximately 3.1 lp/mm. Percent contrast was obtained to be 1.22 corresponding to detector exposures of 0.15 mR and 1.13 mR and 0.61 for detector exposure corresponding to 5.7 mR. No ghosting was observed. EXI reproducibility was found to be within 2% of average. No artifacts or distortions were observed. Maximum time to refresh was 20 seconds for Table Top and 19 seconds for Table and Wall Bucky respectively. **Conclusion:** Detailed performance evaluation of digital flat detectors is an important part of a comprehensive quality assurance program.

TU-FF-A4-03

Post-Processing Dead Pixel Evaluation for Digital Detectors

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Purpose: To investigate and determine a viable method for determining the absolute number of dead pixels from a diagnostic x-ray digital acquisition output. **Method and Materials:** In a digital receptor, dead pixels are averaged over surrounding pixels to present an image without artifacts. The absolute number of dead pixels is in general not provided by the manufacturer, but a relative number of pixels from the last check may be reported. Due to the relative difficulty of gaining access to the raw image values, we focus on the least processed images obtainable from a given unit and employ post-processing techniques to evaluate the pixel information. We use statistical and autocorrelation algorithms to evaluate the likelihood that a given pixel point or line of pixels is aberrant from the expected random noise resulting from several uniform exposures from a digital acquisition detector. **Results:** We are able to determine that both algorithms provide indications for the line and individual (or grouped) point pixel modifications which are not consistent with random noise. The statistical method (employing both a local and global statistical analysis of noise variations) shows both geometries (point and line defects) but requires statistical averaging over several images to provide relevant point geometry data (we use a minimum of three images to average). The autocorrelation method provides results without the need for averaging. However, by employing the criteria that each of the three images must meet the same correlation requirements, we increase the confidence of the final evaluation results through redundancy. **Conclusion:** We have developed two independent methods for determining the overall dead pixel information from a digital acquisition detector given three uniform

exposures. Both methods provide data for point and line geometries and can be used to provide initial and time logged progression of absolute pixel drop out with time.

TU-FF-A4-04

Intensity Modulation Patterns for Regional Exposure Control with Multiple Angle Slot Scan Imaging: Simulated Annealing Optimization Technique Approach

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Purpose: To study the feasibility of using simulated annealing algorithm to determine the intensity modulation patterns for regional exposure control with multiple angle slot scan imaging. **Method and Materials:** We acquired a digital image from the chest radiography and then processed with a 2-D Gaussian filter as an exposure equalization mask. Slot scanning exposures at evenly spaced angle between 0 and 180 degrees were used to achieve the ideal exposure distribution. An optimization technique, simulated annealing, was used to search the best intensity modulation patterns. This method is based on the theory of statistical physics and uses Boltzmann probability distribution to locate the minimum energy state. An objective function was mathematically constructed and Metropolis scheme was incorporated into the numerical computation. Various tuning parameters such as the control temperature setting for the annealing schedule were explored and the best combination was empirically chosen. We also calculated the percent root mean square error to quantify the results. **Results:** A wide range of scanning angles was tested in the study. For 8 projection angles, it took 10 minutes to complete the intensity modulation patterns search in a single processor computer and the percent root mean square error was 12.0%. The percent root mean square error can be further reduced by adding the number of scanning angles. **Conclusion:** Our study indicated that simulated annealing technique has the potential to determine the optimized intensity modulation patterns. Current work is focused on the reduction of both the computing time and percent root mean square error. Other optimization techniques such as the conjugate gradient method and the applications of parallel computing methods to accelerate the search algorithms are to be investigated.

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TU-FF-A4-05

Temporal Subtraction of Lateral Chest Radiographs

R Engelmann, S Armato*, D Doshi, W Sensakovic, A Starkey, H MacMahon, The University of Chicago, Chicago, IL

Purpose: Radiologists routinely compare multiple radiographs of the same patient to identify interval change in anatomy and pathology. The temporal subtraction images that facilitate this comparison have been limited to posteroanterior radiographs. Since the lateral view provides diagnostically important information, the purpose of this study was to develop an automated method for the subtraction of temporally sequential lateral chest radiographs and to evaluate the quality of the resulting images. **Method and Materials:** An automated method was developed to digitally subtract pairs of lateral chest radiographs. First, multiple rotated versions of the "previous" lateral radiograph were generated. For each of the rotated previous images, the apex of the lungs was identified through gray-level profile analysis. A 251 x 215 mm subimage was then extracted near the apex and used as a template for cross-correlation with the "current" radiograph. The translation and rotation parameters that yielded the highest correlation were used to rigidly transform the “previous” radiograph, which was then subtracted from the current radiograph to yield the temporal subtraction image. 30 pairs of lateral chest radiographs were subtracted. An observer rated the quality of each temporal subtraction image using a 1 ("very poor") to 5 ("excellent") scale. **Results:** The average registration accuracy rating was 4.0. 83% (25/30) of the subtraction images were rated as "acceptable" or better (3.0 or higher). **Conclusion:** Our technique for the automated subtraction of temporally sequential lateral chest radiographs generates a high percentage of subtraction images with acceptable registration accuracy. Such a method is expected to provide a valuable supplement to the conventional posteroanterior temporal subtraction images that have proven beneficial in the diagnostic evaluation of interval change in chest radiography.

S.A. and H.M. hold warrants to shares in R2 Technology, Inc.; H.M. consultant for Riverain Medical and Median Technologies.

TU-FF-A4-06

Variation in Dual-Energy Chest Radiography Among Systems Using Identical Digital Flat Panel Detectors

V Devaraju*, C Willis, MDACC, Houston, TX, UT MD Anderson Cancer Center, Houston, TX

Purpose: To study the variation of dual-energy chest radiography systems by measuring Spectral Quality Factor (SQF) and subtracted-image Noise Quality Factor (NQF) defined by Alvarez, Seibert, and Thompson (2004) [1]. SQF depends on the x-ray energy spectrum and detector DQE. NQF is a measure of noise in the subtracted image, which depends on SQF and detected signal levels. **Method and Materials:** Stepwedges of aluminum and polycarbonate duplicating the original work and a 4.8 mm thick acrylic slab were radiographed in dual energy chest mode at 120 and 60 kVp using 15 systems (XQ/i, XR/d, and XR/dII; GE Medical Systems; Milwaukee, WI). Exposure levels of approximately 16, 24, 47, and 57 mR were measured free-in-air, corrected to the surface of the acrylic slab. SQF was calculated from effective linear attenuation coefficients, slopes of logarithm of pixel values behind each step relative to an uncovered area versus step thickness from raw images of each stepwedge at low and high energy. NQF was the slope of SNR^2 in the soft-tissue image of the smallest step of the polycarbonate stepwedge versus entrance exposure. **Results:** Alvarez, et al. compared three dual-energy detector technologies, reporting results in relative terms, including variation of ±5% in SQF for an individual unit like ours. Our SQF was approximately 1.2×10^{-8} mm^{-2} ±14%. They reported NQF of 0.18 mR^{-1} estimated from Fig.10 using images subtracted by their own algorithm. Our NQF was approximately 0.16 mR^{-1} ±9% using images subtracted by the clinical system. **Conclusions:** SQF and NQF are useful indicators of dual energy system performance that can be determined in a practical setting with clinical systems. Values for our flat panel systems are in general agreement with previous reports.

WEDNESDAY, AUGUST 2

Imaging Continuing Education Course — Room 330 A

CE: Breast Imaging Physics and Technology - III

WE-A-330A-01

Breast CAD in the Digital Era

M Giger*, Univ Chicago, Chicago, IL

Use of output from a computerized analysis of a breast image by radiologists may help them in the tasks of detection or diagnostic, and potentially improve the overall interpretation of breast images and the subsequent patient care. Many factors motivate the attempts to aid or automate radiological diagnosis. Inadequacies in interpretation performance may be due to the presence of image noise or normal anatomical structure as well as to known limitations in the human search and perception process. Developments in breast CAD have led to clinically-used detection systems in screening mammography and pre-clinical classification systems for diagnostic breast imaging. Diagnostic breast CAD systems provide output for the characterization of lesions on special-view mammography, breast sonography, and breast MRI in order to aid in patient management decisions, such as biopsy decisions. As imaging continues to expand in the digital era, computer-aided diagnosis (CAD) may become an integrated tool in the online diagnostic workup of suspect breast lesions using multi-modality images and advanced PACS. This presentation reviews research in computerized analysis of mammographic, sonographic, and magnetic resonance breast images for detection and diagnosis. It will include the characterization of lesions and the estimation of the probability of malignancy for use in the diagnostic workup of suspect lesions. CAD systems in diagnostic workup usually involve having the computer extract the margin of the lesion from the surrounding parenchyma, extract characteristics (features) of the lesions, merge these computer-extracted features into an estimate of the probability of malignancy, and as an option, retrieve automatically similar lesions from an online reference library. The aim of CAD in diagnostic workup is to increase classification sensitivity and specificity as well as to reduce intra- and inter-observer variability. While the breadth and depth of CAD is increasing, continued and expanded efforts are needed for collecting and confirming databases, establishing methods for evaluation, integrating effectively and efficiently with PACS and RIS systems, and providing means for clinical evaluation.

Learning objectives:

1. To appreciate the development of CAD in multi-modality imaging for detection and diagnosis of breast cancer.
2. To understand the benefits and challenges as CAD moves into the digital era and is integrated with PACS and HIS.
3. To recognize the necessary steps for advancing and integrating CAD clinically.

COI: Maryellen Giger is a shareholder and consultant, and receives research funding from R2 Technology, Inc.

Imaging Continuing Education Course — Room 330 D

CE: PET Physics and Technology - III

WE-A-330D-01

PET Scanner Quality Assurance

B Kemp*, Mayo Clinic, Rochester, MN

Quality assurance of PET scanners must be performed on a regular basis to maintain and confirm proper scanner performance. These procedures should track system stability and be sensitive to changes in scanner operation. The quality control and calibration of a PET scanner includes detector and electronic characterizations such as adjustment of PMT gain, definition of crystal and energy maps and coincidence timing calibration. These characterizations are applied to the PET data during acquisition. A PET quality control regimen includes system corrections such as normalization, calibration and, in the case of non-PET/CT systems, blank scans. The calibration correction is used to convert the reconstructed image pixel values into activity concentration and it may be used to compensate for the axial sensitivity variation of the scanner. These characterizations are applied to the PET data after acquisition.

The NEMA PET NU2-2001 standard should be followed for acceptance testing. This standard uses a polyethylene phantom of 700mm axial length with a line source to measure scatter fraction, count losses and randoms. The measurement of sensitivity is conducted with a line source surrounded by known absorbers, and the sensitivity with no absorbers can be found by extrapolation. The intent of the image quality measurement is to mimic a whole body scan using a torso phantom containing hot and cold spheres of various diameters (representing lesions) in a warm background.

This presentation will focus on the calibrations and corrections required to maintain proper system performance. The presentation will also describe the rationale and methodology of the NEMA NU2-2001 performance standards.

Educational Objectives:
1. Describe the calibrations required to properly detect the location of a coincident event.
2. Describe the post acquisition corrections required to minimize image artifacts.
3. Describe NEMA NU2-2001 PET performance standards.

Imaging Continuing Education Course — Valencia A

CE: Medical Imaging Informatics - III

WE-A-ValA-01

Characteristics and Performance Evaluation of Digital Image Displays

S J Shepard*, U. T. M. D. Anderson Cancer Center, Houston, Texas

As departments make the transition from screen/film imaging to soft-copy interpretation, the emphasis of the quality control program must shift from controlling the quality and consistency of the images on film to controlling the quality and consistency of the image on the display device. A fundamental feature of this new QC process is the assessment of the performance of the display device itself. This presentation will cover the performance characteristics of CRT and LCD displays and quality assurance and assessment techniques for primary display systems. The information given reflects the recommendations of the American College of Radiology (ACR) as outlined in their Technical Standard for Teleradiology (Rev. 2002) and the American Association of Physicists in Medicine (AAPM) in On-line Report #3 (OR-3), the report of Task Group 18 (TG18), entitled Assessment of Display Performance for Medical Imaging Systems. The presentation will introduce the performance requirements of the ACR and AAPM for primary displays and will provide instructions for performing display assessment based on TG18 methodology. Recommendations for the instrumentation necessary to perform these tasks will also be made. As a summary, important characteristics of a display QC program will be outlined.

Educational Objectives
1. Understand the technology behind CRT and LCD display devices and how they affect display performance.
2. Gain familiarity with the information contained in OR-3 and the standards for display performance and QC in the ACR standard for teleradiology.Gain familiarity with the procedural details involved with evaluation of primary diagnostic display devices according to the methods outlined in the pending TG18 task group report.
3. Be able to establish and support an on-going primary display QC program in a PACS-based clinical environment.

Outline
Display Performance Requirements
ACR

AAPM
Instrumentation
Luminance Meter
Light baffle
Illuminance Meter
Diffusion Box
Pocket Telescope (30x – 50x)
Magnifying Glass (2x)
Plastic ruler
Masks
Test patterns
TG18 QC (General Purpose QC and Geometric distortion)
TG18 LN (Luminance response)
TG18 UNL-10 and –80 (Luminance uniformity, Chromaticity, Dead pixel evaluation)
TG18 AFC (Noise assessment)
TG18 CX (Resolution)
TG18 VG (Veiling glare)
TG18 LPH and LPV (Dead pixel evaluation)
Procedures
Luminance Response
Max Brightness & Contrast
Luminance Uniformity
Reflection
Specular Reflectance
Diffuse Reflectance
Luminance of the Reflected Illuminance
Reflection & Ambient Lighting
Specular reflection of illuminated background objects
Diffuse reflection effect on Lmin and contrast
Resolution (CRT only)
Noise
Geometric Distortion (CRT only)
Veiling Glare (CRT only)
Pixel Defects (LCD only)
Acceptance Tests
Luminance Response
Luminance Uniformity
Reflection
Noise
Resolution (CRT)
Geometric Distortion (CRT)
Veiling Glare (CRT)
Pixel Defects (LCD only)
Monthly (CRT) / Quarterly (LCD) Tests
Luminance response
Evaluation of the TG18-QC test pattern
Experience
Self-calibrating displays
Test frequency

References
1. Thronworth, WT, et al, Standards and Accreditation Committee, ACR, 2003, http://www.acr.org/departments/stand_accred/standards/pdf/teleradiology.pdf
2. Samei, E, et al, Acceptance Testing & Quality Control of Electronic Devices for Soft-copy Display, AAPM (Draft document), http://deckard.mc.duke.edu/~samei/tg18

Educational Objectives:
1. Participants will be familiar with primary display performance requirements published by the ACR and the AAPM.
2. Participants will be able to perform primary display assessment according to procedures outlined in AAPM TG18 (draft).
3. Participants will be able to design and implement a robust quality control program for primary displays in a PACS environment.
4. Participants will be able to identify specific performance tests for CRT displays and for LCD displays.

Imaging Continuing Education Course Valencia B
CE: Computed Tomography Physics and Technology - III

WE-A-ValB-01
Multi-Slice CT Image Reconstruction
J Hsieh*, GE Healthcare Technologies, Waukesha, WI

Over the past decade, x-ray computed tomography has experienced tremendously technological advancements: the introduction of helical/spiral and multi-slice/volumetric acquisition. These advancements not only allow improved image quality and enable new clinical applications, but also significantly increase the technical challenges associated with image reconstruction.
The first part of this lecture will cover the fundamentals of image reconstruction. For the ease of understanding, we start with an explanation of the central slice theorem (Fourier slice theorem). Both theoretical and intuitive approaches are used to illustrate the concept. The reconstruction algorithm is then extended to fan beam geometry by mathematical derivation and graphic description.
Using the central slice theorem as the foundation, reconstruction algorithms for helical acquisition are discussed in the second part of the lecture. We analyze, for single slice, the major difference between helical and step-and-shoot acquisitions. Implications of different reconstruction approaches on image quality and computational complexity are also discussed.
Cone beam reconstruction discussion will start with one of the most popular algorithms: FDK algorithm. The derivation of the algorithm from the fan-beam case is first described and its extension to helical/spiral acquisition is then presented. The lecture ends with a discussion on some of the most recent advances in cone beam reconstruction, including both approximate and exact methods.
Jiang Hsieh is an employee of GE Healthcare Technologies.

Educational Objectives:
1. Learn the fundamentals of x-ray CT reconstruction.
2. Understand recent advancements in reconstruction algorithms.

Therapy Continuing Education Course Room 224 A
CE: IMRT Modeling Influence on Planning

WE-A-224A-01
IMRT Modeling Influence On Planning
J Dempsey*, University of Florida, Gainesville, FL

The quality of an intensity modulated radiation therapy (IMRT) treatment plan can be strongly influenced by the physical and mathematical models underlying a clinical planning system. This lecture provides an overview of the models that are commonly employed for purposes of treatment planning for megavoltage (MV) photon-beam IMRT achieved through multi-leaf collimator (MLC) delivery. IMRT treatment planning models will be examined which include models of: ionizing-radiation dose computation; fluence-map optimization; MLC delivery sequence optimization; dosimetric plan evaluation; and "biologic" plan evaluation. Models will be studied with focus on the assumptions, merits, and limitations involved with different models. The differences between reality and the models will be explored. Emphasis will be placed on plan characteristics that exist in reality but are not reflected in the model of the IMRT delivery. The influence of the algorithms employed to implement the models will also be discussed including methods that involve discretization, rounding, and limited numerical precision. Practical examples that demonstrate the influence of modeling differences on IMRT plan quality will be presented.

Educational Objectives:
1. Understand the influence of the choice of physical models employed in clinical IMRT
2. Understand the assumptions, merits, and limitations involved with different IMRT planning models
3. Review the conditions where IMRT modeling is suspect and requires careful scrutiny in clinical implementation

Therapy Continuing Education Room 224 C
Course
CE: Daily Localization III: Tomotherapy

WE-A-224C-1
Daily Localization III: Tomotherapy
S Meeks*, M. D. Anderson Cancer Center Orlando, Orlando, FL

Helical tomotherapy using the Hi-ART II is analogous to helical CT imaging where the gantry and the couch are in simultaneous motion. Hence, beam delivery is continuous over all 360 in transverse planes about the patient. Temporal beam modulation is achieved by using a binary multi-leaf collimator. In addition to its ability to deliver IMRT, the Hi-ART II has the ability to obtain helical megavoltage CT (MVCT) images. These MVCT images have adequate spatial and contrast resolution for image guidance, and also for identification of many soft-tissue structures. The incorporation of daily three dimensional soft-tissue imaging into the radiotherapy process also enables dose recalculation and periodic evaluation of the treatment delivery during a course of radiotherapy. Hence, the subsequent treatment delivery can be modified using a systematic feedback of the geometric and dosimetric information in the previous fractions. This requires many components as feedback, including CT guidance to achieve soft tissue localization, dose recalculation, dose accumulation, treatment evaluation, re-contouring, and re-optimization.

This lecture will provide an overview of the physical characteristics of the Hi-ART II, acceptance testing and commissioning, image quality tests, image registration, basic quality assurance, and an overview of clinical applications. Finally, system limitations and future developments will be addressed.

Educational Objectives
1. Understand the basics concepts of helical tomotherapy
2. Understand the basic QA requirements and system limitations association with helical tomotherapy
3. Understand the workflow and issues related to clinical applications of helical tomotherapy, including acquisition, reconstruction, registration and patient alignment.
4. Understand the possibilities of daily soft-tissue imaging for patient alignment and evaluation of treatment accuracy

Therapy Continuing Education Room 230A
Course
CE: NCI Talk on Funding

WE-A-230A-01
NCI Talk On Funding
J Deye*, National Cancer Institute, Bethesda, MD

The National Institutes of Health is composed of 27 Institutes and Centers, with the National Cancer Institute (NCI) being the oldest and the National Institute of Biomedical Imaging and Bioengineering (NIBIB) the youngest. Medical physicists have a major stake in the pursuits of these institutes since they have a large influence on everything from the research that is funded to the clinical protocols and methods that are employed in both therapy and diagnosis.

Yet these institutes are themselves experiencing very significant extrinsic and intrinsic factors that affect the ways that they interact with the medical community. A partial list would include: the NIH budget in the post-doubling period; the creation of NIH-wide Roadmap Initiatives and NCI-wide Enterprise Initiatives; the adaptation of the NIBIB to the other Institutes; budget set-asides for the war on terrorism; the dawning of translational research methods; the blurring of boundaries between disciplines; and an increasing role for industry, to name a few.

The ramifications of these changes will be explored with regard to the institute budgets, priorities and relationships; and the presentation will outline some of the current research agendas and the mechanisms which are used to implement them.

Educational Objectives:
1. Understand the structure and processes involved in NIH funded research.
2. Understand the issues surrounding the NIH budget
3. Understand how to develop a research proposal

Imaging Continuing Education Room 330 A
Course
CE: Radiation Safety and Risk Management - III

WE-B-330A-01
Shielding Design Workshop: PET/CT
M Martin*[1], G Frey*[2], (1) Therapy Physics, Inc., Bellflower, CA, (2) Medical Univ of South Carolina, Charleston, SC

The application of the structural shielding design techniques and goals as outlined in AAPM Task Group Report 108: *PET and PET/CT Shielding Requirements* Medical Physics (Vol. 33., Issue 1 (2006)) will be the basis for this practical course. As the use of PET and PET/CT units expands rapidly in the medical arena, the requirements for providing adequate radiation protection for both occupational personnel in these facilities and the public in uncontrolled areas around them necessitate the involvement of a qualified medical physicist. The many areas involved in implementing a PET/CT program including the Hot Lab, Patient Uptake Rooms, Patient Restrooms, Scan Rooms, and Disposal areas will be used as practical examples of typical structural shielding designs and evaluation methods.
The testing of PET shielding insures that the shielding is properly installed and that individuals do not exceed the radiation exposure levels required by applicable regulations and ALARA policies. Testing of PET and PET/CT shielding is a complex multidimensional problem since there are multiple sources and the radiation is emitted isotropically from the patients. Thus efficient testing can both save time and reduce radiation exposure to the physicists doing the testing. This course will discuss efficient methods for shielding testing. It will also review the instrumentation available to physicists for making the measurements. Practical methods of testing of a PET/CT facility will be presented.

Educational Objectives:
1. Understand the exposure factors to be used for currently used PET isotopes to determine required structural shielding to meet exposure limits for occupational personnel and the public.
2. Understand the effectiveness of existing and additional structural shielding materials that provide radiation protection and methods to calculate the required amounts of these materials.
3. Understand the methods to be used to evaluate the adequacy of PET and PET/CT installations to insure adequate shielding has been provided to meet applicable state and ALARA requirements.

Imaging Continuing Education Room 330 D
Course
CE: Radiography Physics and Technology - III

WE-B-330D-01
Digital Image Processing in Radiography
M Flynn*, Henry Ford Health System, Detroit, MI

In digital radiography, the transmitted x-ray beam recorded by a detector is first recorded as raw data related to the energy deposited in the sensitive region of each pixel. Raw data is then transformed to a 'For Processing' image by correcting for gain non-uniformity and bad pixels. Finally, the 'For Processing' image is transformed to a 'For Presentation' image that is intended for viewing.

The processes used in the presentation transformation have become an ssential element of image quality. These processes include exposure recognition, grayscale rendition, edge restoration, noise reduction, and broad area equalization. The numeric methods used to implement these processes will be reviewed and related to current commercial image processing solutions.

Educational Objectives:
1. Understand how image processing is integrated. into a sequence of steps used in generating a radiograph.
2. Conceptually understand the component processing steps and their effect on image quality.
3. Learn how certain commercial systems implement processing.
4. Understand how processing can be adjusted by a medical physicist to achieve consistent presentation characteristics.

Imaging Continuing Education Course Valencia A
CE: Fluoroscopy Physics and Technology - III

WE-B-ValA-01
Interventional Fluoroscopy Imaging Equipment - What to Know Before You Buy
J Cusma*, Mayo Clinic, Rochester, MN

The number of fluoroscopy-guided interventional procedures performed continues to grow, accompanied by an increasing complexity in these clinical procedures. Technical improvement in the x-ray imaging equipment utilized for these procedures continues at a fast pace as well, driven in part by the clinical requirements but also by the overall advance of computational technology. It remains a challenge for an interventional laboratory to ensure that its imaging equipment provides state-of-the-art capabilities in a manner consistent with internal workflow and economic factors. The situation is further complicated by the fact that the replacement cycle for this equipment can be on the order of a decade - an extraordinarily long time in the arena of technological advances. These factors place a high premium on careful analysis of the requirements and technical capabilities of the fluoroscopic and angiographic equipment being considered by a laboratory for purchase.

The primary factors to be addressed in the purchase of modern interventional x-ray imaging equipment remain the same as with any imaging equipment: the type of clinical procedures for which the equipment will be utilized. Since traditional clinical boundaries continue to evolve, equipment must be flexible to perform a range of procedures throughout a patient's anatomy. The specific concerns are the combination of cardiac, peripheral vascular, and neurovascular procedures to be performed. The answer to that question will have significant implications for the size of detector, image acquisition parameters, image processing options, and the display and storage requirements. As noted, the replacement cycle is long and these systems are not easily upgraded after purchase so identification of the procedure mix is important at the outset.

Once the procedure requirement is determined, equipment can be evaluated with regard to how well it meets those requirements. Among the options related to the type of procedure are type of detector, field-of-view, x-ray tube capacity, and image processing options. Functionality relevant for all types of procedures include: (i) patient exposure monitoring and exposure reduction methods; (ii) image analysis and quantification; (iii) storage capacity; (iv) options for archive and display. In addition, local factors such as service and maintenance must also be considered.

Educational Objectives:
1. Understand the relationship between clinical procedure requirements and the corresponding capabilities of interventional fluoroscopy equipment.
2. Understand the range of options available in fluoroscopy and angiography x-ray systems.
3. Be able to assess and compare different imaging systems and prioritize local factors important for purchase decisions.

Imaging Continuing Education Course Valencia B
CE: MRI Physics and Technology - III

WE-B-ValB-01
Physics Procedures for ACR MRI Accreditation
C Keener*, Medical & Radiation Physics, Inc., San Antonio, TX

In recent years, the American College of Radiology (ACR) Magnetic Resonance Accreditation Program (MRAP) has been adopted by over 3000 sites, nearly half of the estimated MRI facilities in the United States. Those sites agree to follow a weekly QC program set up and monitored by a qualified medical physicist or MR scientist. They also agree to undergo initial and annual equipment performance evaluations by a qualified medical physicist/MR scientist. There are several published documents, including the *ACR Phantom Testing Guidance* and the *2004 ACR MRI QC Manual*, which describe the tests and the performance criteria. These documents are helpful in providing guidance on submitting phantom images for accreditation. However, they allow considerable discretion to physicists doing these tests, and the scanners change more frequently than the published guidance.

A consulting medical physicist may see a variety of scanners, each for a short period of time, and needs to provide the sites with useful recommendations beyond the pass/fail status of the phantom tests. The physicist must gather this information from existing data and tests performed with the ACR and other available phantoms. This lecture will describe information which can be derived from those data and how it may be used for improving MR image quality.

Educational Objectives:
1. Learn the current status of the ACR MRAP program and the role of the medical physicist in that program.
2. Understand how to perform required phantom and annual tests on various scanners and the performance criteria for those tests.
3. Understand how the results of those tests can be combined and analyzed to troubleshoot problems.
4. Understand how QC test and phantom availability and results may vary depending on scanner manufacturer.

Therapy Continuing Education Course Room 224 A
CE: Shielding III: Practical Examples, Including IMRT, TBI, SRS

WE-B-224A-01
Shielding III: Practical Examples, Including IMRT, TBI, SRS
J Rodgers*, Maryland Regional Cancer Care LLC, Silver Spring, MD

The recently published NCRP Report No. 151, "Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities", presents updated methods and data for radiation therapy room shielding design. These calculational methods are applied in examples representing the more common shielding design situations. A radiation therapy vault with a maze barrier and intended for use with IMRT and TBI procedures is the principal example. Detailed calculations of the barriers and door shielding structures are presented. Procedures for evaluating compliance with the NRC licensing constraint on dose equivalent in-any-one-hour are presented. An example of a high-energy room where photoneutron production is of concern is presented with focus on assessing the dose equivalent at the entrance and the maze door design.

Therapy Continuing Education Course Room 224 C
CE: 4D / Gated Treatment

WE-B-224C-01
Respiratory Gated and Four-Dimensional Tumor Tracking Radiotherapy
P Keall*, Virginia Commonwealth University, Richmond, VA

Human anatomy and physiology change with time. Solid tumors also exhibit temporal behavior, particularly when assaulted with radiotherapy. In the era of image-guided therapy, technology is being developed to explicitly account for these changes with time, both in cancerous and healthy tissue. One source of temporal anatomic changes is respiratory motion, which affects organs (and tumors) in the thorax, abdomen and

pelvis. This motion causes deleterious effects during the imaging, planning and delivery of radiotherapy:

- *Imaging:* Motion causes a misrepresentation of the positions, shapes and volumes of both the tumor and normal anatomy during CT scanning and other imaging modalities. This phenomenon potentially leads to geometric misses of the tumor during treatment delivery.
- *Planning:* If tumor motion is present, and not explicitly being accounted for, larger safety margins are needed. These larger safety margins increase normal tissue dose, increase treatment-related toxicity and limit dose escalation.
- *Treatment delivery:* The motion of the tumor during treatment can cause unplanned under- and over-dosage regions, particularly for IMRT.

Clinical studies have demonstrated evidence of a dose response for both tumors and healthy lung tissue. Thus it is hypothesized that increased targeting accuracy will allow for dose escalation, facilitating improved local control, and/or a reduction in treatment-related toxicities, predominantly pneumonitis. Two methods that can account for respiratory motion and hence increase targeting accuracy are respiratory gated radiotherapy and four-dimensional (4D) tumor tracking radiotherapy.

An implicit assumption common to all techniques that base delivery decisions on the respiratory signal is that the tumor motion is correlated with this signal. The strength of this correlation is dependent on the patient, tumor type and location and the source of the respiratory signal.

Respiratory gating is a method of synchronizing radiation with respiration, during the imaging and treatment processes. Image acquisition occurs either by prospectively triggering acquisition during a certain part of the breathing cycle, or retrospectively sorting the sinogram/images based on the part of the breathing cycle in which they were acquired. Respiratory gating has been successfully clinically implemented in a number of academic and community settings for both conformal and IMRT treatments.

4D radiotherapy can be defined as the explicit inclusion of the temporal changes in anatomy during the imaging, planning and delivery of radiotherapy:

- *4D CT imaging:* Acquisition of a sequence of CT image sets over consecutive phases of a breathing cycle.
- *4D planning:* Designing deliverable treatment plans on 4D CT image sets.
- *4D treatment delivery:* Continuous delivery of the 4D treatment plan throughout the breathing cycle.
- 4D delivery can be achieved by continuously aligning the beam and patient during treatment using a robotic linac, DMLC, block motion or couch motion.

Educational Objectives:

1. Understand the rationale for accounting for respiratory motion during imaging, treatment planning and radiation delivery.
2. Learn about the clinical implementation of respiratory gated radiotherapy.
3. Learn about 4D tumor tracking radiotherapy.
4. Understand the advantages and disadvantages of respiratory gated and tumor tracking radiotherapy.

Conflict of Interest: PI's research supported by Varian Medical Systems.

Therapy Continuing Education Course — Room 230A

CE: Pediatric RT Issues

WE-B-230A-01

Understanding Pediatric Radiation Therapy

A Olch*, University of Southern California Keck School of Medicine and Childrens Hospital Los Angeles, Los Angeles, CA

Most Medical Physicists working in radiotherapy departments see few pediatric patients. This is because, fortunately, children get cancer at a rate about 30 times smaller than adults. Children have not smoked, abused alcohol, or been exposed to environmental carcinogens for decades, and of course, have not fallen victim to the aging process. Children get very different cancers than adults. Breast or prostate cancers, typical in adults, are rarely seen in children but instead a variety of tumors occur in children that are rarely seen in adults; examples are germinomas, ependymomas and primitive neuroectodermal tumors, which require treatment of the child's brain or neuroblastoma, requiring treatment in the abdomen. The treatment of children with cancer using radiation therapy is one of the most challenging planning and delivery problems facing the physicist. This is because bones, brain, breast tissue, and other organs are more sensitive in children than in adults while the required tumor dose is frequently above 50 Gy. Because most therapy departments treat mostly adults, when the rare 8 year-old patient comes to the department for treatment, the physicist may not understand the clinical issues of his disease which drive the planning and delivery decisions. There is a new set of dose constraints different from the adult patient, which, depending on the site of treatment, may require changing the routine beam arrangement for that site. Additionally, children are more prone than adults to developing secondary cancers after radiation. This fact has important implications for the choice of delivery techniques, especially when considering IMRT. For bilateral retinoblastoma, an irradiated child has a 50% chance of developing a second cancer by age 50.

In this presentation, an overview of childhood cancers and their corresponding treatment techniques will be given. These can be some of the most complex treatments that are delivered in the radiation therapy department. These cancers include Leukemia treated with total body irradiation, medulloblastoma, treated with craniospinal irradiation plus a conformal boost to the posterior fossa, neuroblastoma, requiring focal abdominal irradiation to avoid kidney, liver, and vertebral body damage, retinoblastoma, requiring treatment to an eye while minimizing dose to surrounding tissues, and a variety of other tumors which occur anywhere in the body. Case studies will be presented showing the treatment technique and resulting dosimetry, highlighting the objectives for tumor coverage and organ-at-risk sparing. Practical issues that have to be faced when treating children will also be discussed such as daily sedation and immobilization.

Finally, most children with cancer are treating within a clinical trial administered by the Children's Oncology Group. Examples of the protocol physics requirements will be discussed as well as the physicist's responsibility for providing data to the Quality Assurance Review Center.

The presenter is Chief of Physics at one of only two radiotherapy departments in the country that treat exclusively children (Chidlrens Hospital Los Angeles).

Educational Objectives:

1. Improve understanding about childhood cancer and treatment with radiation
2. Understand treatment planning and delivery issues specific to children
3. Understand physicist responsibility for clinical trial participation

Imaging Scientific Session — Room 330 A

Image-Guided Interventions

WE-C-330A-01

Robust Tracking of Interventional Tools Under X-Ray Fluoroscopy Using Particle Filters

S Siddique*[1], D Hatzinakos[2], D Jaffray[1], (1) Princess Margaret Hospital/University of Toronto, Toronto, Ontario, CA, (2) University of Toronto, Toronto, ON, CA

Purpose: Motion estimation is an important problem. In diagnostic and therapeutic interventions, intraoperative motion estimation is needed to guide interventional tools with high precision. In radiation therapy, intrafraction motion estimation is essential to improve the precision with which therapeutic radiation is delivered. The purpose of this study is to estimate the pose (location and orientation) of interventional tools such as needles in an X-ray fluoroscopic sequence using a particle filter. **Method and Materials:** *Tracking Algorithm:* The tools were tracked using a particle filter. Two models are of concern in such an implementation – (i) the *observation model* was defined on the output of an edge detector by taking transverse and longitudinal samples of the tool, and (ii) the *dynamic model* was assumed to be given by Brownian motion.

*Experimental Setup:*The accuracy of the tracking algorithm was validated on an X-ray fluoroscopy test bench. A modified anthropomorphic Rando™ phantom was placed in the field-of-view in order to emulate the background presented by a patient. Two sites on this phantom were used – the pelvis and the thorax. The pelvis presents a case of low signal while the thorax presents a cluttered background. The tool to be tracked was attached to a linear actuator and moved in known increments while capturing fluoroscopic images. The acquired image sequence was then sampled to generate new image sequences for testing the tracking algorithm. **Results:** The algorithm was robustly able to track the tool under a low signal in the abdomen, and under dense clutter presented by the ribs in the thorax. The rms error in each case was found to be as little as 0.7mm and 0.12mm, respectively. **Conclusion:** This study demonstrates the robustness of estimation under noise and clutter that can be achieved when tracking tools in a fluoroscopic sequence using a particle filtering approach.

WE-C-330A-02

Cone-Beam CT for Image-Guided Head and Neck Surgery: Assessment of Dose and Image Quality Using a C-Arm Prototype

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Purpose: To quantify radiation dose to patient and staff during intraoperative cone-beam CT (CBCT)-guided head and neck surgery, and investigate 3D imaging performance as a function of dose. **Method and Materials:** Dose and image quality measurements were acquired on a mobile C-arm modified at our institution to provide flat-panel CBCT. Imaging dose was measured in a custom-built 16 cm cylindrical head phantom at four positions (isocenter, anterior, posterior, and lateral) as a function of kVp (80–120 kVp) and C-arm trajectory ("tube-under" and "tube-over" 180^{o} orbits). In-room exposure was measured at positions around the operating table and up to 2 m from isocenter. 3D image quality was assessed in CBCT reconstructions of an anthropomorphic head phantom containing contrast-detail spheres (11-103 HU; 1.6-12.7 mm). The contrast-to-noise ratio (CNR) was evaluated across a broad range of dose (0.6–23.3 mGy). **Results:** Dose in the 16 cm phantom (100 kVp; "tube-under" orbit) was 0.059 (isocenter), 0.022 (anterior), 0.10 (posterior), and 0.056 (lateral) mGy/mAs. Dose to the eyes (anterior) was reduced by a factor of 10 for "tube-under" versus "tube-over" orbits. In-room exposure for a typical CBCT scan (~10 mGy to isocenter) ranged from 33 mR at the anesthetist position, to <0.5 mR at 2 m from isocenter. CNR increased as the square root of dose, with excellent visualization of bony and soft-tissue structures in the anthropomorphic head phantom achieved at ~3mGy and ~10mGy, respectively. ***Conclusion:*** The prototype C-arm CBCT system demonstrates excellent visualization of bony and soft-tissue structures at dose levels low enough for repeat intraoperative imaging. High-performance image-guidance with respect to bony and soft-tissue anatomy was achieved at doses <~3mGy and <~10mGy, respectively. For guidance of head and neck surgery, significant dose sparing to the patient's eyes (a factor of 10) is achieved using a "tube-under" (rather than "tube-over") 180^{o} orbit.

WE-C-330A-03

Seed Segmentation in C-Arm Fluoroscopy for Brachytherapy Implant Reconstruction

S Vikal*[1], A Jain[2], A Deguet[2], D Song [3], G Fichtinger[2], (1) RWTH Aachen University of Technology, DE, (2) Johns Hopkins University, Baltimore, MD, (3) Johns Hopkins University School of Medicine, Baltimore, MD

Purpose: Intra-operative dosimetry in prostate brachytherapy critically depends on discerning the 3-D locations of implanted seeds. The accuracy of 3-D seed reconstruction step is, in turn, limited by the accuracy with which the position and orientation of individual implanted seed in the fluoroscopic images can be found. A method for robustly segmenting the seeds in fluoroscopic images is proposed here. Methods and Materials: The process of determining the locations and orientations of implanted seeds is sub-divided into three main steps. In the first step, the image is segmented by shape-size based morphological approach to eliminate background noise and do away with non-uniform brightness of the image, to get seed-like regions. These regions are either single seeds or overlapping multiple seed clusters. In the second step, the regions are analyzed and classified definitively, in a two-phase statistical process coupled with information extraction from original intensity image, into two classes: single seed and overlapping multiple seed cluster. In the third step, the region belonging to overlapping multiple seed cluster is resolved into its constituent individual seeds through a simple and novel technique. **Results:** The proposed algorithm was tested on a set of ten clinical fluoroscopic images. The algorithm correctly determines the seeds with overall average of 99.57%. The clusters are not correctly resolved only in two images (2 clusters each, 1.7% and 1.6% of total seeds in respective implants). One false positive (noise labeled as seed) each is reported in two images, both the cases being where the tip of catheter appears to be of the size and shape of seed. **Conclusions:** The algorithm builds on an existing framework of morphological processing and provides further improvements in classification and cluster resolution. The algorithm appears to be robust and accurate despite the poor resolution of clinical images.

WE-C-330A-04

Effect of Projection Angles Used in Multi-View Reconstruction (MVR) Using Images From a Microangiographic (MA) Detector and An Image-Intensifier (II) System

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Purpose: The sensitivity of a new 3D Multi-View Reconstruction (MVR) angiography technique to the projection angles used is evaluated by comparing 3D centerlines calculated from combinations of three projections acquired from two imaging systems with that from micro-Cone Beam CT (μCBCT), which is taken as truth. **Method and Materials:** A 3D centerline of a contrast-filled carotid vessel phantom was reconstructed from image data acquired using a custom-made μCBCT system with a microangiographic (MA) detector (45 μm pixels, 4.5 cm field-of-view (FOV)). Projection images of the same phantom were also acquired using the MA and an image intensifier (II) detector system (120 μm pixels, 4.5 in FOV) on a C-arm x-ray unit. The MVR technique was used to compute 3D centerlines for 12 combinations of projection angles. Each 3D MVR centerline was aligned with the μCBCT "true" 3D centerline using a Procrustes technique, and a root-mean-square (RMS) deviation was calculated. **Results:** The average RMS deviation for the MA-MVR centerlines is 25 μm with a standard deviation of 3 μm over the 12 different projection-angle combinations, whereas the average RMS deviation for the II-MVR centerlines is 41 μm with a standard deviation of 4 μm over these same combinations. The RMS deviation as a percent of the internal vessel diameter, 0.75 mm, is 3.3% for the MA and 5.5% for the II and appears to be independent of view selection. **Conclusion:** For the MVR technique, the improved resolution of the MA resulted in improved centerline determination compared to the II system. For both detectors, the selection of a particular projection set had little effect on the RMS centerline deviation. The low RMS deviations for both detectors indicate that the MVR technique can provide accurate 3D centerlines.

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WE-C-330A-05

Segmentation of Radioactive Seed in 3D Ultrasound Images for Intraoperative LDR Prostate Brachytherapy

Z Wei*, London Health Sciences Center, and Robarts Research Institute, London, Ontario, Canada; A Fenster, Robarts Research Institute, and the University of Western Ontario, London, Ontario, Canada

Purpose: Develop and evaluate an algorithm to automatically localize implanted radioactive seeds in 3D ultrasound images for dynamic intraoperative low dose rate (LDR) brachytherapy procedures, in which all phases of the procedure are performed in one session to deal with variability in the current prostate brachytherapy. **Method and Materials:** Intraoperative seed segmentation in 3D TRUS images is achieved by performing a subtraction of the image before the needle has been inserted, and the image after the seeds have been implanted. The seeds are searched through a thresholding operation in a "local" space determined by the needle position and orientation information, which are obtained from a needle segmentation algorithm. To test this approach, 3D TRUS images of

the agar and chicken tissue phantoms were obtained. Within these phantoms, dummy seeds were implanted. The seed locations determined by the seed segmentation algorithm were compared with those obtained from a volumetric cone-beam flat-panel micro-CT scanner and human observers. **Results:** Evaluation of the algorithm showed that, the *rms* error in determining the seed locations using the seed segmentation algorithm was 0.98*mm* in agar phantoms, and 1.02*mm* in chicken phantoms. In both agar and chicken phantoms, 100% of the implanted seeds were correctly identified using the seed segmentation algorithm. **Conclusions:** The seed segmentation algorithm is insensitive to different materials, as the errors of the algorithm are almost the same in agar and chicken phantoms. This work indicates the potential to achieve an intraoperative post-implant dosimetry. Integration of this algorithm into a clinical brachytherapy system is now ongoing and clinical testing with patients will take place in the near future.

WE-C-330A-06

FEA and Phantom Tests of Ultrasound Temperature Maps During Thermal Therapy

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Purpose: The ability to noninvasively monitor heating patterns during radiofrequency ablation therapy would provide invaluable guidance to clinicians during these procedures. We are investigating ultrasonically recorded and scaled "apparent tissue displacements", caused by sound speed changes and tissue expansion, for generating temperature maps during ablation. This paper reports FEA simulations and experiments in novel phantoms to determine whether ultrasound can successfully record temperatures. **Method and Materials:** FEA models were applied to determine the temperature distribution from a radiofrequency ablation electrode in liver. FEA analysis enabled creation of both temperature and tissue expansion maps during simulated procedures. The expansion maps in turn were combined with sound speed changes and used to model ultrasound echo data at intervals during the ablation. In addition, experimental data were acquired using a reusable slurry phantom with embedded sensors surrounding an ablation electrode. Frames of echo data were acquired using a linear array transducer during a 15-minute heating sequence. For both simulated and real data, two-dimensional cross-correlation of echo signals from successive frames yielded accumulated tissue displacements. Scaled gradients of these displacements estimate local temperatures. **Results:** Temperature maps generated from simulated echo signals correspond well to the underlying temperature maps created with FEA. The zone of elevated temperatures can be easily visualized on these maps. Isothermal curves on the temperature maps may be useful in determining areas that may have incurred cell death or tissue necrosis. Preliminary results indicate good correlation between fiber optic temperature sensor measurements and ultrasound temperature measurements over $1cm^2$ ROI's surrounding the probe. **Conclusion:** Temperature maps estimated using ultrasound signals correspond well to the FEA generated temperature maps. Temperature mapping can therefore be used to visualize the zone of heating during a radiofrequency ablation procedure. This result is confirmed by temperature measurements done in an ultrasound phantom.

WE-C-330A-07

Radiofrequency Ablation Electrode Displacement Elastography

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Purpose: Elastography can be used to image the position and location of thermal lesions created using radiofrequency (RF) ablation. A challenge, however, when applying this technique to guide treatment of liver tumors is that of producing a controlled compression of the tissue. We are testing a new method, 'electrode displacement elastography', for producing elasticity images of ablation therapy treatments. This paper presents results of tests in a custom elastography phantom. **Method and Materials:** An elastography phantom containing a stiff inclusion (50 kPa) embedded in a soft (11kPa) background was used. A discarded RF electrode was mounted firmly into the inclusion with the handle extending outside the phantom container. A stepper motor applied small (0.1mm) displacements while the phantom was imaged using an ultrasound machine equipped with a research interface, acquiring raw echo data before and after small perturbations of the electrode. One-dimensional cross correlation was used to estimate displacements. Finite element analyses were also performed to characterize the contrast-transfer efficiency (CTE) of the conversion from the underlying modulus domain to the observed strain domain. **Results:** On elastograms the inclusion has a characteristic halo appearance, similar to that observed in *in-vivo* tests of this technique. Strain contrast is consistently higher than the underlying modulus contrast, confirmed by a study of the CTE. On simulated strain images, stiffer inclusions in softer backgrounds have CTE values in excess of 0 dB. **Conclusions:** Feasibility of electrode displacement elastography is shown. The strain contrast observed exceeds the underlying modulus contrast, for stiffer inclusions. This characteristic of the method may provide RF ablation practitioners with added lesion contrast in situations where the actual stiffness ratio between the lesion and surrounding normal tissue is not significantly greater than 1:1.

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WE-C-330A-08

An Efficient Morphometric Skull Atlas for Image Guided Radiotherapy

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Purpose: We describe an efficient method to extract the outer skull features from CT transaxial slices for use in IGRT. **Method and Materials:** A Bezier curve B(t) was fit to four sections of the outer skull on CT slices at 0.3cm spacing. B(t) is a parametric equation defined by two anchor points (A1,A2) and two control points (C1,C2) such that $B(t)=(1-t)\wedge 3A1+3t(1-t)\wedge 2C1+3t\wedge 2(1-t)C2+t\wedge 3A2$ for $0\leq t\leq 1$. The parameter t is sampled to create a sequence of points at 0.3cm interval. The atlas consists of all the Bezier points and can be transformed by rotation R and translation T such that B(t)'=RB(t)+T. Thirty-two points on the anterior-posterior and right-lateral Portal Images are digitized for analytical computation of setup error. The position and orientation (i.e. pose) of the atlas with the minimum Hausdorff Distance (HD) between the PI points and the outer projected atlas contour determines the homogenous transformation. **Results:** Manual draw-by-wire technique can take up to 15 minutes per slice. The total time is reduced by 50% for similar size patients in nearly identical positions. The overall accuracy was determined to be 0.15 cm. A semi-automatic technique with improved accuracy of 0.1 cm was investigated using simulated annealing. An automatic algorithm using monochromatic bit maps with edge detection was also evaluated. For 30 CT slices, the complete atlas is defined by only 360 points. Setup error for a clinical case was measured and the effects of pure rotation mimicking translation quantified. **Conclusion:** We have demonstrated that a series of four piecewise continuous Bezier curve segments can accurately extract the outer skull feature from a CT transaxial scan. A patient specific atlas can be quickly morphed from the generic atlas. The atlas has been shown to be clinically useful for 3D analysis of setup error and theoretical quantitative analysis of pure rotation.

WE-C-330A-09

Dynamic, MultiModality Imaging: Temporal Precision and US Artifact Reduction

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Purpose: Herein we describe the development of a dynamic fusion technology for ultrasound (US) and other static 3D data sets. We tested whether the high US frame rate is sufficient to accurately track objects subject to respiratory motion. In addition, we used the spatial registration functions of the system to test whether aggressive compounding of US images would be efficacious in terms of artifact reduction and boundary detection. **Materials/Methods:** The system's dynamic spatial accuracy was tested using a phantom translated at a velocity of either 4 or 16 mm/s. To test inaccuracies due to video processing we offset the arm and video frame data in single frame increments. Static 3D US data sets were acquired incorporating an acoustic obstruction. Data sets were reconstructed using images from multiple angles of interrogation. Similar experiments were performed to assess the system's ability to reduce

reverberation artifacts and tested on a human subject. **Results:** By correcting for video processing latency, the system was able to track object motion to 0.2 and 0.5 mm for speeds of 4 and 16 mm/s, respectively. Aggressive image compounding was able to reveal objects that were otherwise obstructed from a single view. Reverberation artifacts were reduced, in addition to enhancing certain object boundaries . These results were present although less obvious in early human testing. **Conclusions:** Our imaging system is spatially accurate over a range that permits interrogation of an adult abdomen from a wide range of angles. The system's ability to track respiratory motion has been demonstrated. Aggressive compounding demonstrated that obstructed test objects could be visualized by non-intelligently summing images from varying angles. Soft tissue boundaries and other US artifacts may also benefit from application of the technology.

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WE-C-330A-10

Brightness-Based Methods for Correcting Beam-Former Sound Speeds

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Purpose: The speed of sound (SOS) varies among patients and spatially within a patient. Differences between the SOS assumed in the beam former and that of tissue defocuses B-mode images. A global effective SOS value can be chosen to maximize image quality. This study investigates brightness based methods for SOS corrections. **Method and Materials:** The beam former assumed SOS in a Siemens Antares machine was varied while imaging two phantoms having different SOS's (ATS539-1440m/s and RMI403-1540m/s). Three methods were used to quantify resultant image quality changes: visual inspection, zeroth order statistics over a region of interest (ROI) and axial/lateral variation of echo signals arising from discrete reflectors. Peak brightness (PB), mean brightness (MB) and mean of brightness squared (MBS) were measured. **Results:** Visual inspection showed image sharpness improvement at an appropriate SOS. The optimal SOS values correlate with phantom specifications, but are lower (30-70m/s). Operating conditions affect the optimal SOS. The brightness varies partially due to the fractional overlap of the transmission/reception focal zones, drifting apart with depth.
MBS over a ROI proved superior to MB in distinguishing an optimal SOS. Both measures suffered drift problems with SOS for ROI's far from the transmit focus. Including structures in the ROI affects the ability to generate an SOS peak.
The lateral extent of a bright spot/glint selected either visually or by a simple search, varies with the assumed SOS. PB and MBS of line signals showed a peak around the optimal SOS. Axial signals are more robust. The maxima at glints result in minima for neighboring axial lines demonstrating good focusing. **Conclusions:** Visual inspection and glint analysis yield consistent SOS's that improve image quality. SOS accuracy for diagnostic use is limited due to effects of operating conditions of the machine and needs further investigation.

Imaging Symposium Room 330 D

Image Science 2020: Perspectives on the Future of Imaging Physics

WE-C-330D-01

The Future of Image Science

I Cunningham*, Robarts Research Institute, London, ON, CA

The characterization and classification of image quality in radiographic imaging is a complex and illusive goal. It involves understanding the physics of x-ray interactions and how these influence statistical properties of image signals and noise. It requires an understanding of how observers can extract non-random structures from random (and sometimes not random) image details. Finally, it requires an understanding of how observers are able to extract clinically meaningful information from the complicated clutter of background structural information. As processes responsible for producing image signals are often non-linear, non-stationary, multi-dimensional and task dependent, simpler metrics of image quality and detector performance are at best idealized approximations. Scientists have attacked this multi-faceted problem from a number of directions. As a result, a wide spectrum of terminology and concepts have become commonplace. This talk will address some aspects of how far "image science" has come and where it may be going. It will highlight accomplishments that have become established in both academic and commercial fields, and problems that have not been solved. Hopefully, improved understanding of these issues will enable the development of better detectors and systems and improved patient outcomes.

Educational Objectives:
1. Understand issues that influence image quality and observer performance for simple tasks
2. Understand limitations of simple metrics
3. Understand some directions being followed to better understand what determines image quality for the development of better detectors and systems

WE-C-330D-02

Image Science and CAD: In Pursuit of a Fundamental Theoretical Basis for CAD Development

R Nishikawa*, Univ Chicago, Chicago, IL

Computer-aided diagnosis is still a very immature field, with very little theoretical framework upon which it is based. This is a major limitation in both developing systems and in evaluating them in a meaningful way. It is clear that in the future CAD will play a greater role in radiology, both as secondary reader and as a primary reader. The current clinical implementation of CAD is as second reader to radiologists. This will shift to CAD being used by a physician assistant and CAD as the primary reader and the radiologist as the secondary reader. Ultimately, CAD will be the only reader, at least for a subset of cases.

However, to increase the development and adoption of new CAD systems, the field needs a better fundamental foundation. This foundation will come from several areas. First, as we gain a better understanding of human observers, we can use this information not only to develop more accurate CAD algorithms, but also importantly, to design CAD systems that can be integrated into the radiologists' workflow more fully. Second, models of CAD techniques need to be developed. In analogy to modeling ideal observers and human observers, much can be gained from modeling CAD schemes. Third, a thorough understanding of the interaction between the image and the CAD technique is needed. For example, if the shape of the NEQ curve of the image receptor changes, can we predict how the performance of the CAD technique will change.

Medical imaging technology is rapidly changing. The current paradigm for developing CAD systems – try different techniques on hundreds of images – cannot keep pace with these changes, especially as new imaging systems are developed, where clinical images are scarce. Our goal should be to develop the field to the stage where it will be possible to model the imaging system's characteristics and then, guided by models of human observer performance, select from an array of image processing, artificial intelligence and pattern recognition techniques a group of techniques that will produce the optimum CAD system.

This talk will present my vision for the future of CAD and what is necessary for the field to make rapid progress.

Educational Objectives:
1. Discuss future roles of CAD as both a secondary and the primary reader.
2. Explain the fundamental limitations of CAD development.
3. Discuss one possible approach to overcoming the limitations in the future.

WE-C-330D-03

Bioinformatics, the Multiple-Biomarker Classifier Problem, Complexity, and Uncertainty

R F Wagner*, Center for Devices & Radiological Health, FDA, Rockville, MD

The most celebrated landmark of modern bioinformatics has been the sequencing of the human genome. Early in the project it was commonly believed that humans have about 100,000 genes and as the project neared

completion the estimates came down into the neighborhood of 25,000-30,000. Hidden Markov Models (HMM) are used to carry out statistical parsing of the "linguistics" of such bioinformation. Such massively complex analysis has been facilitated by modern developments in massively complex hardware and software--but such analysis is naturally accompanied by great uncertainties. At a lower level of complexity are the algorithms used for computer-aided diagnosis in medical imaging, and at an intermediate level are the tools under current development for fusing multiple biomarkers--for example, from a large number of spectral lines in mass spectroscopy of protein fragments in blood samples and other mutliplex data from protein and gene microarrays. This talk will review the uncertainties in measured performance of such diagnostic tests as a function of the sample sizes available for training and testing as well as the dependence on the number of fused biomarkers and the complexity of the associated statistical learning algorithm. A strategy for designing large trials based on pilot studies will be outlined.

Educational Objectives:
1. Understand the multiple-biomarker classifier problem
2. Understand the uncertainties in its performance assessment due to finite training and testing
3. Understand the dependence on number of biomarkers and complexity of statistical learning algorithm

Joint Imaging/Therapy Valencia A
Scientific Session
Modeling of Intra-Fraction Organ Motion

WE-C-ValA-01
Evaluation of Image Quality in 4DCT and Improving Temporal Accuracy

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Purpose: To assess the effect of incorrect assignment of respiration phases and irregular breathing on 4DCT image quality. Artifacts are manifested as deformations in the reconstructed images and quantitative effects are measured along with qualitative evaluations. Modifications to the current 4DCT implementation are recommended. Methods and Materials: For the evaluation of image artifacts, we used a motion simulation platform and simulated the respiration patterns of real patients. Artifacts due to inaccurate phase sorting are quantitatively evaluated by comparing differences in the volumes of spherical phantoms with and without the presence of phase assignment problems. Artifacts due to irregular breathing are demonstrated using 4DCT and recommendations are made for modifying the standard acquisition mode to enable gating for motion reproducibility. The advantage of this modified acquisition is proved using an electronic portal imager. **Results:** Review of clinical 4D scans performed in our clinic showed discrepancies in the phase assignments for about 45% of the cases when compared to our independent check. Significant image artifacts are also observed and measured as a function of the respiration motion amplitude and target size. Volumetric inaccuracies of up to 43% are measured. For the evaluation of irregular breathing, our proposed technique of gated imaging for the reproducibility of the respiration proved to yield superior image integrity when compared to standard acquisition mode. **Conclusions:** We identified two sources of quality degradation factors associated with 4DCT images and performed quantitative evaluations of associated artifacts. We conclude that for improved image reconstruction, an independent check of the sorting procedure should be performed for each clinical case; also we recommend a modification to the 4DCT acquisition technique to include gating of the x-rays for the reproducibility of the respiration pattern. **Conflict of Interest:** Research supported by GE Medical Systems.

WE-C-ValA-02
The Impact of 4D Breathing Motion Effects Versus Tissue Heterogeneity in Lung Cancer Treatment Planning

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Purpose: To investigate the relative magnitudes and clinical importances of the dosimetric effects related to 4D breathing motion and tissue heterogeneity for thoracic tumors treatment planning. **Methods:** Scans were acquired at normal exhale/inhale breathing phases. The target was the union of the exhale and inhale GTVs, uniformly expanded by 5mm(ITV). Patients were planned with both AP/PA and 3-D conformal plans using the exhale ("static") dataset, assuming unit density, for 100±5% ITV dose coverage. Each of these plans was further used to calculate: (a) heterogeneous "static" dose; (b) homogeneous cumulative dose; (c) heterogeneous cumulative dose. The same number of MU were used for each of the calculations and was based on the homogeneous "static" plan. Cumulative dose distributions consisted of a time-weighted sum of exhale and inhale doses. Doses were calculated using the DPM_MC code which includes secondary electron transport for the heterogeneous computations. **Results:** Relative to unit-density plans, tumor EUD, and lung NTCP increased in the heterogeneity corrected plans; primarily due to the reduced beam attenuation through lungs and the larger than coin-size tumors investigated. In comparing 4D cumulative dose plans with static plans, clinical EUD and NTCP estimates were relatively unchanged. The insignificant tumor EUD change was a consequence of good target design, while the small lung NTCP change was due to its large volume effect. Accounting for tissue heterogeneity resulted in average changes of 10% in MLD. Accounting for 4D breathing motion effects resulted in <1% changes in MLD from the static value. The magnitude of these effects was not correlated with the dose distribution conformality. **Conclusions:** In this study we found that tissue heterogeneity effects are likely to have a larger clinical significance on tumor (if ITV is properly designed) and normal lung clinical treatment evaluation metrics than occurs with 4-D respiratory-induced changes.

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WE-C-ValA-03
The Use of CT Density Changes at Internal Tissue Interfaces to Monitor Respiratory Induced Lung Tumor Motion

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Purpose: To describe a non-invasive method to monitor the motion of internal organs affected by respiration without using external markers or spirometry, to apply the method to construct 4D-CT datasets, to test the correlation with external markers, and to calculate any time shift between the datasets.

Method and Materials: Ten lung cancer patients were CT scanned with a General Electric Fast 4-Slice CT scanner operating in ciné mode. An external signal was also acquired simultaneously using the Real-Time Position Management (RPM) Respiratory Gating System (Varian Medical Systems). We retrospectively reconstructed the raw CT data to obtain consecutive 0.5s reconstructions at 0.1s intervals to increase image sampling. We defined regions of interest containing tissue interfaces that move due to breathing on each axial slice and measured the mean CT number as a function of respiratory phase. We constructed 4D-CT data sets by retrospectively sorting each image set based on the respiratory phase determined by the mean CT number curve. The external marker and tumor motion were directly correlated using the sample coefficient of determination, r^2. Any time shift between the two data sets was calculated by shifting the tumor motion curve until r^2 was maximized. **Results:** Only three of the ten patients showed correlation higher than r^2=0.80 between tumor motion and external marker position. However, after taking into account time shifts (ranging between 0s and 0.4s) between the two data sets, all ten patients showed correlation better than r^2=0.8. **Conclusions:** 4D-CT acquisition using an internal method improves the temporal registration of CT images affected by respiratory motion without the need for external markers or spirometry. A non-invasive method to directly correlate the motion of external markers and internal organs can be used to help guide decisions regarding the validity of the RPM system for respiratory gated radiotherapy on a patient-specific basis.

WE-C-ValA-04
Derivation of the Tumor Position From External Respiratory Surrogates with Periodical Updating of External/internal Correlation

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Hospital, Sapporo, Japan, (5) Hokkaido University, School of Medicine, Sapporo, Japan

Purpose: To develop techniques that can derive the tumor position from external respiratory surrogates through periodically updated internal/external correlation. **Method and Materials:** A simple linear function is used to express the correlation between tumor and surrogate motion. The function parameters are established during patient setup session with both tumor and surrogate positions measured at 30Hz rate. During treatment, the surrogate position, constantly acquired at 30Hz, is used to derive the tumor position. Occasionally, a tumor image is acquired to enable the updating of the correlation function. Four update methods are investigated. (a) Line shift. (b) Fit model - through point. (c) Fit model - extra weight. (d) Function difference - fit point. **Results:** Tumor and external surrogate motion demonstrates a high degree of correlation however it dynamically changes over time. Occasionally updating the correlation function leads to more accurate predictions than using external surrogates alone. At the lowest tumor imaging rate tested in this work (0.1Hz) an accuracy improvement of 10% over the prediction by the mere use of external surrogate was observed for the best update method. Update methods (a) and (b) derive the tumor position with larger accuracy than (c) and (d) in case of high imaging rates. The opposite is observed in case of low imaging rates. **Conclusion:** Occasional calibration of the tumor/external surrogate correlation during treatment substantially increases the accuracy of the tumor localization compared to tumor position derivation by using the external surrogate alone.

This work is partially supported by CenSSIS.

WE-C-ValA-05

Comparison of Thermocouple and Spirometer for Monitoring Patient Breathing

J Ha*, B Yi, C Yu, University of Maryland, Baltimore, MD

Purpose: To show the feasibility of using a thermocouple for monitoring patient breathing and to compare its breathing signal with that of a spirometer. **Method and Materials:** A mask covering the nose-and-mouth region was used to channel the subject's breath to a K-type thermocouple (TC) and a spirometer. Two different placements of the TC were studied: either it was inserted through a side hole of a plexiglass tube connecting the mask and spirometer or in the oxygen inlet of the mask. This setup allowed simultaneous readings of the temperature and air volume in synchrony. The temperature change is a response to the amount of heat deposited to or taken away from the TC junction. Both signals were collected at the sampling rate of 100 KHz using a data acquisition board. The acquisition program was written in LabWindows. **Results:** The TC temperature and measured air volume are found to be highly correlated at the two locations. When placed in the oxygen inlet away from the direct inhale/exhale air streams, the sensing temperature shows a cubic dependence on the flow rate. When placed in the plexiglass tube where it was more directly exposed to the inhale air, the temperature exhibits some hysteresis on the flow rate. At both locations, the temperature signals show no drift for10 minutes of breathing. **Conclusions:** The proposed TC system can be used as an external surrogate to monitor patient breathing at both TC locations. It has the advantages of spirometry in that it directly responds to the lung air flow. The setup is very easy and has no setup error. However, it does not have the drift problem that plagues spirometry. It is also relatively inexpensive. All these qualities make it attractive and suitable for respiratory gating or tracking to deliver external beam radiation therapy.

WE-C-ValA-06

Characterizing and Modeling Patient Respiratory Patterns for Radiation Therapy

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Purpose: Lung tumor breathing motion is a function of both the breathing depth (tidal volume) and breathing rate (airflow). Treatment planning for lung tumors will require a patient-specific tumor motion model. An understanding of the patient's typical breathing cycle will be critical to accurate treatment planning predictions for linear-accelerator gating or tracking. This work examines patient-breathing characteristics to determine the patterns and stability of the breathing cycle. **Method and Materials:** A total of 34 patients (with and without lung cancer) were scanned with a previously described 4DCT protocol under synchronized tidal breathing monitoring. We examined the scatter plot of air flow against tidal volume for the entire scan session. A 2D histogram was then generated by calculating the frequency of data points falling into each tidal volume-airflow window. The 2D histogram depicted the probability that the patient breathed at certain tidal volume and air flow window. We evaluated the breathing consistency of the three patients with multiple scans. **Results:** There was no significant differences in the breathing period (P=0.11) or in the peak-to-peak amplitude (P=0.22) between patients with lung cancers and patients with upper-abdomen cancers. The 2D histogram revealed two different breathing patterns: patients who spent more time breathing at the end of exhalation (20 patients), exhibiting a characteristic volume-flow curve, and patients who spent the majority of time inhaling and exhaling (14 patients). The latter patients did not spend any appreciable amount of time between successive breaths. For the three patients with two sessions, the mean frequency difference between corresponding tidal volume-airflow windows was <0.3%. **Conclusion:** We characterized patient breathing by examining the tidal volume-airflow plot and histogram. The results showed two different breathing patterns suggesting that not all patients are appropriate for gated radiotherapy. All three patients showed high consistency in two scan sessions.

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WE-C-ValA-07

Statistical Analysis of Respiratory Motion and Knowledge Discovery

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Purpose: Quantified characterization and better understanding of tumor respiratory motion is valuable for understanding of respiration, motion-included treatment planning, online prediction, and real-time control algorithm for dose delivery in image guided radiotherapy. There are two goals of this work: (1) to discover the correlation among various motion variables so that we can understand patient respiratory better and (2) to build an analytical system for online motion modeling and prediction during real-time treatment delivery. **Method and Materials:** Statistical analysis of tumor respiratory motion has been performed over 48 real patient data. Quantified information of different motion characteristics, including amplitude, frequency, velocity and the mean positions are computed over different granularities. Sample granularities include a breathing state, a breathing cycle, a treatment session, a patient and the whole patient population. Association rules among different motion characteristics are mined and formulated. **Results:** We have implemented the software packages for statistical analysis and correlation presentation. Quantified motion information have been computed and displayed. The spatio-temporal changes of these properties are studied. Knowledge of respiratory motion and the underlying physiological explanation have been exploited. The probability distribution functions of various correlations among different properties have been calculated and visualized. **Conclusion:** Different statistical analyses over a set of tumor motion characteristics have shown that there are some general rules regarding tumor motion. The analytical results help us to obtain new knowledge and to understand the physiological actions of tumor motion and to treatment moving tumor more efficiently. **Conflict of Interest:**

WE-C-ValA-08

Development of a Patient Specific Respiratory Motion Model for Predicting Dose to Moving Organs During Radiotherapy

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Purpose: Respiratory motion is an important limitation to accurate calculation of dose to organs in the thorax and abdomen during treatment. We describe a model to estimate 3-dimensional motion in patient CT images. This model can be parameterized by navigators such as a signal from a respiratory monitor, or diaphragm position measured in fluoroscopy. We evaluate the accuracy of the model in predicting anatomic changes in respiration-correlated CT (RCCT) images of lung cancer patients. **Method and Experiment:** Our method makes use of deformable image

registration, thereby automating the model calibration and providing a complete determination of 3D trajectories for all tissue voxels of the moving organs. Calibration of the model uses a series of RCCT images. Each 3D image in the series is tagged by two navigators: current diaphragm position and precursor position which distinguishes between the inspiration and expiration portion of the respiratory cycle. Nonrigid registration is used to calculate the deformation field that maps each 3D image to a reference 3D image at end expiration. We perform a principle component analysis (PCA) to determine the 3D deformation parameterized by navigators. We evaluate the model by comparing the predicted 3D images with actual 3D images at different phases in the breathing cycle. **Results:** For RCCT images, predicted images calculated from the first two principal components at different respiration phases are found to accurately reproduce anatomic motion observed in the actual images, indicating the model's ability to predict the voxel trajectory anywhere in the cycle. Furthermore, the model can predict motion induced changes that were not in the original image set, such as deeper and shallower breathing. **Conclusion:** Preliminary experimental results indicate that the proposed method is a potentially useful tool for treatment planning and evaluation of dose to moving organs when patient breathing is monitored.

WE-C-ValA-09

A Biological Lung Phantom for IGRT Studies

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Purpose: We are evaluating the feasibility of a dynamic biological lung phantom for IGRT studies, with the initial goal of developing a reliable phantom suitable for use in validation of deformable registration and volume rendering studies of the lung. The properties of an ideal lung phantom would include complex geometry, anisotropic inflation, and composition, lobar structure and internal airway architecture similar to that of human lung. **Method and Materials:** Preserved swine lung was obtained and compared to human lung. The prepared lung was statically inflated to different volumes using a regulated nitrogen supply, and can also be dynamically inflated using a medical ventilator. The inflated phantom was imaged on a GE Lightspeed CT scanner. Volume rendering of the CT image data was performed to visualize and determine coordinates of airway bifurcations. **Results:** Preserved swine lung was determined to be comparable to human lung in terms of tissue radiological and physical properties, lobar structure, airway architecture, volume and mass. Rendered airway vs. physiologic airway dimensions are undergoing verification by dissection. Analysis of CT images and volume rendering data demonstrates that the airway architecture may be followed to at least the 5th airway bifurcation, yielding a conservative minimum of 31 reproducible anatomic landmarks evenly distributed throughout the lung. By visual inspection, it is possible to follow the displacement vector of these landmarks in sequential images. **Conclusion:** Initial analysis shows that a swine lung phantom meets a number of the requirements of a reliable and functional phantom for validation of deformable registration and volume rendering methods. Reference points generated using the CT/volume rendering technique may be useful as a validation tool for both feature- and intensity-based deformable registration techniques. Ongoing study will evaluate the potential of the lung phantom for use in planning, delivering, and validating 4D IGRT.

WE-C-ValA-10

4D Cone-Beam CT (CBCT) Using An On-Board Imager

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Purpose: To develop an artifact-free four-dimensional (4D) cone-beam CT (CBCT) imaging technique for image-guided radiotherapy, and to optimize the image quality, scanning time, and patient radiation dose with respect to acquisition parameters such as the number of gantry rotations, gantry-rotation speed, and x-ray tube current. **Method and Materials:** A Varian Trilogy^{TM} system was employed for this study. To sort CBCT projections in terms of patient breathing phase, a CT-opaque fiducial was adhered to the patient skin and tracked automatically in the projection space, and the phases of the fiducial trajectory were used to tag the projections. Projections after phase-binning were subsequently reconstructed to yield 4D-CBCT images. To reduce/eliminate view-aliasing artifacts due to limited number of projections in each phase, both "multiple-rotation" and "slow-gantry-rotation" strategies were investigated. Quantitative evaluation and comparison were performed with a motion phantom for the following acquisition settings: (i)varying number of gantry rotations (1~8) with all other scanning parameters kept the same; (ii)varying x-ray tube current together with the number of rotations while keeping the radiation dose constant, namely, 1-rotation-80mA, 2-rotation-40mA, 4-rotation-20mA, and 8-rotation-10mA; (iii)varying gantry-rotation speed (1deg/sec~8deg/sec).Three patient cases were used in the study. **Results:** The image quality, represented by relative error (RE), varied nonlinearly with the number of rotations: RE reduction became less pronounced as the number of rotations increased. After 3~5 rotations, the benefit resulting from more rotations started saturating. When the dose level was kept the same, the images of 1-rotation-80mA and 8-rotation-10mA acquisitions had the largest and smallest REs, respectively. Similar RE reduction behaviors were found when slowing down the gantry-rotation speed. For the patient cases, 4D images were obtained with negligible motion or view-aliasing artifacts. **Conclusion:** We have successfully demonstrated that the commercially available OBI system can be utilized to acquire artifacts-free 4D-CBCT images without increasing the patient radiation dose.

Joint Imaging/Therapy Symposium Valencia B

Imaging the Tumor Micro-environment and Response to Therapy

WE-C-ValB-01

Introduction

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The reasons for the failures of conventional anticancer therapies are varied and multiple. It is however, becoming increasingly clear that physiological conditions in tumors, arising primarily from inadequate and non-uniform vascular networks, can play significant roles in the lack of therapeutic responsiveness of neoplasms. However, the impact of the tumor microenvironment far exceeds its direct effects on therapeutic treatment modalities. For example, tumor hypoxia can contribute to processes that directly favor malignant progression and increased metastasis. New treatment strategies aimed at improving tumor response through targeting cells existing in these microenvironments or the aberrant tumor vasculature itself, therefore are of high interest. Non-invasive imaging strategies may aid not only in identifying tumors that would be effectively treated with such strategies but also in providing effective means of monitoring treatment effectiveness and therapeutic outcomes.

WE-C-ValB-03

Functional Analysis of Tumor Vasculature Post Antiangiogenic Intervention with Argeted Anti-VEGFR2 Therapy

A.S. Brown*, Sunnybrook & Women"s College Health Sciences Centre, Toronto, CA

High frequency ultrasound biomicroscopy (UBM) permits in vivo assessment of anatomical and physiological parameters at high resolution. The ability to image the mouse noninvasively facilitates longitudinal studies with repeated measurements in the same animal over time, to follow normal development or disease processes as well as response to therapeutic intervention. Anatomical images are obtained using B mode, giving a cross-section of the structure of interest. Anatomical changes can now be quantitated using 3D volumetric B mode imaging, and rendered to give an accurate contour of the structure of interest. 3D UBM may be used to measure organ growth through normal development, or to compare treated versus untreated populations in mouse models of human disease. High frequency ultrasound Doppler permits measurement of blood flow velocity in selected vessels of interest. Recent advances in blood flow analysis, including speckle variance analysis, permit investigation of blood flow velocity of flow velocities down to 100 microns per second, as well as perfusion alterations.

High frequency ultrasound imaging modes, imaging strategies, and post-processing methods used to generate anatomical and physiological data will be discussed.

Educational Objectives:
1. Understand the concepts behind high frequency ultrasound imaging modes
2. Understand the application of high frequency ultrasound to image development and disease processes in the mouse, including experimental design, data acquisition and data processing
3. Understand therapeutic study design, data acquisition and analysis using UBM

WE-C-ValB-04

Magnetic Resonance Spectroscopy Detects Metabolic Changes Upon Chemotherapy of Human Non-Hodgkin's Lymphoma Xenografts

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A preliminary multi-institutional study has recently demonstrated that ratios of the hosphomonoesters, phosphoethanolamine plus phosphocholine, to NTP of human non-Hodgkin's lymphoma (NHL) easured by 31P MRS before initiation of therapy can identify about 2/3 of the patients who will not exhibit a complete local clinical response**.** These patients should be encouraged to undergo more aggressive alternative therapy, which entails some risk of mortality but also offers hope of response, remission or cure**.** However, the limited sensitivity of 31P MRS limits its application mostly to large, superficial tumors**.** We have, therefore, been developing much more sensitive 1H MRS and MRI methods to examine smaller tumors**.** Here we report studies of mouse xenografts of the most common form of human NHL and the only form that exhibits cures (in about 1/3 of the patients) -- diffuse large B-cell lymphoma (DLCL2)**.** In vivo 1H MRS using a selective multiple quantum coherence pulse sequence (Sel-MQC) detected decreases of lactate and total choline in DLCL2 tumors treated with three cycles of CHOP (cyclophospamide, doxorubicin, vincristine, prednisone) chemotherapy with Bryostatin added to suppress expression of the mdr1 gene**.** Single voxel localized spectroscopy (STEAM) detected decreases in choline and lactate/lipid that accompanied response**.** These changes correlated decreases in phosphomonesters detected by 31P MRS with tumor growth delay**.** In vivo data were correlated with data on tumor extracts**.** Our data suggest that 1H MRS may provide a very sensitive method for detecting early response of human NHL to chemotherapy; 1H MRI studies of response are in progress.

Professional Course Room 230A
Medical Errors II

WE-C-230A-01

The Application of Error Reduction QA Philosophy in HDR Brachytherapy

B Thomadsen*, University of Wisconsin, Madison, WI

Routine quality assurance (QA) in brachytherapy developed quickly through the 1990s, and fairly standard practices became common. The reports of Task Groups 40, 56 and 59 established formalized, accepted standards for QA in brachytherapy, and textbooks covered QA procedures in detail (1). Why, with a solid understanding of QA procedures, were there still many reported brachytherapy medical events, and likely many more unreported or unrecognized? A review of such events (2) notes that for many cases, the facility had QA procedures in place, but they were ineffectual because they either did not cover the situations that evolved or, often, simply were not performed, frequently because of time constraints. Current high dose-rate (HDR) brachytherapy QA focuses heavily on equipment and instrumentation. Very few events resulted from errors in the equipment (although, equipment failures often set the stage), due in part to the extremely high reliability built into the devices and, possibly in part, because of the attention paid to equipment QA by the medical physicists. A soon to be released report from the International Atomic Energy Agency will note that the greatest danger in radiotherapy is not equipment malfunctions but the human activities related to the procedures. (3) Much of the current QA for HDR brachytherapy stems from regulations of the Nuclear Regulatory Commission. Some of the regulations expend effort with little expected return. For example, daily QA requires a check of the door interlock at the room entrance. For many facilities, the operator has the door in clear view during treatments; the probability of a person trying to enter the room during a treatment with a failure of the interlock becomes vanishingly small. With each new source, the length and function of transfer tubes and applicators must be checked. Most of these instruments cannot change their length, and the functioning would be (and should be) determined at each use. Measuring exposure readings outside the HDR room with each source change wastes time. Such requirements divert resources from useful activities. The new paradigm for QA first assesses all the possible ways things can go wrong (and the list is a long one), rating the likelihood of occurrence, and severity of the result if it does happen, and the probability of detecting the failure before it propagates into the event. These ranking provide the priorities for allocating resources for activities to prevent failures This process will naturally place a
greater emphasis on the human role in the procedures.

(1) e.g. BR Thomadsen Achieving Quality in Brachytherapy [Bristol, IOP Press 2000]
(2) B Thomadsen, S-W Lin, P Laemmrich, T Waller , A Cheng, B Caldwell, R Rankin, J Stitt. Analysis of Treatment Delivery Errors in Brachytherapy Using Formal Risk Analysis Techniques. Int J Radiat Oncol Biol Phys 57: 1492 – 1508 (2003).
(3) IAEA Techdoc, Case studies in the application of probabilistic safety assessment techniques to radiation sources. [Vienna, IAEA In press].

Learning Objectives: To understand
1. The problem with the current QA paradigm, and
2. The advantage of the new paradigm

WE-C-230A-02

The Application of Error Reduction QA Philosophy in IMRT

J Palta*, M Huq*, Univ Florida, Gainesville, FL, UPMC Cancer Center, Pittsburgh, PA

The increasing complexity, functionality, and site-to-site variability of modern radiation therapy planning and delivery techniques challenge the traditional prescriptive quality control/quality assurance (QC/QA) programs that ensure safety and reliability of treatment planning and delivery systems under all clinical scenarios**.** The manufacturing industry has historically relied on extensive testing and use of techniques such as probabilistic reliability modeling for developing and maintaining new products**.** Among the most widely used method of risk analyses are Failure Modes and Effects Analysis (FMEA)**.** This is a methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design**.** FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures**.** From a manufacturer's perspective, FMEA is a valuable method to systematically evaluate a device design's potential for inducing user errors**.** User errors are defined as a pattern of predictable human errors that can be attributable to inadequate or improper design**.** When these risk analyses are done early in the development cycle, potential faults and their resulting hazards are identifiable and much easier to mitigate with error-reducing designs**.** These risk management methods are excellent complements to other important user-centered design best practices**.** Risk analysis, or hazard analysis, is a structured tool for the evaluation of potential problems which could be encountered in connection with the use of a device**.** The early and consistent use of FMEAs in the design process allows the engineers to design out failures and produce reliable and safe products**.** FMEAs also capture historical information for use in future product improvement.

We will first review current paradigms of QC/QA issues in IMRT with a goal to define the problems and challenges associated with the implementation of traditional methods of quality assurance**.** This will be followed by a second presentation, which will describe a step-by-step implementation of the aforementioned hazard analyses and error mitigation methodologies of industrial engineering in addressing QA/QC and safety issues in IMRT**.** Such an approach should result in a QA/QC program for IMRT that has a good scientific rationale and justification.

Therapy Scientific Session Room 224 C
Joint Therapy/History Scientific Session: Brachytherapy II

WE-C-224C-01

Buried Emanation: The Dawn of Prostate Brachytherapy

JN Aronowitz*, University of Massachusetts Medical School, Worcester, MA

Although radical prostatectomy was introduced in 1905, few cases of prostate cancer were diagnosed at a stage amenable to curative resection. Megavoltage equipment that could safely deliver a curative dose of radiation to the prostate did not become widely available until the 1960's. To fill this therapeutic void, leading urologists often turned to brachytherapy. This presentation follows the development of intracavitary and interstitial techniques during the second and third decades of the 20th century.

WE-C-224C-02

Preliminary Analysis of ProQura, a Multi-Institutional Database of Prostate Brachytherapy Dosimetry

Z Allen*, P Grimm, G Merrick, W Butler, U Chaudhry, A Mazza, Wheeling Hospital, Wheeling, WV

Purpose: To analyze the ProQura database in terms of patient implant sequence number for each institution to determine evidence for a dosimetric learning curve. **Materials and Methods:** In the ProQura database there are 4,614 patients with postimplant dosimetry implanted at 56 institutions between June 1999 and September 2005. The the mean preimplant prostate volume was 34.5 ± 10.7 cm³, and the mean and median days between implant and postimplant CT scan was 30.4 ± 14.0 and 30 days, respectively. I-125 seeds were used in 3,071 patients, and Pd-103 seeds were used in 1,543 patients. **Results:** The mean V100 was 88.9% ± 8.6% volume and the mean D90 was 101.9% ± 15.1% of the prescribed dose. When analyzed in terms of patient sequence number within each institution, the mean V100 for the first 10 patients was 87.3% ± 9.6% volume, while for the second 10-patient cohort for each institution, the mean V100 was 88.6% ± 10.1% volume ($p = 0.036$). Similarly, the mean D90 for the first 10 patients was 98.9% ± 16.8% prescribed dose, while for the second cohort of ten patients the mean D90 was 102.2% ± 16.1% of prescribed dose ($p = 0.001$). There was little further change in V100 or D90 for subsequent 10 patient institutional groupings of patient sequence numbers. Therefore, the first cohort had a significantly lower V100 and D90 than all subsequent cohorts. The mean monotherapy seed activity per prostate volume was 0.94 ± 0.19 mCi/cm³ for I-125 and was 4.51 ± 0.94 mCi/cm³ for Pd-103. The specific monotherapy seed activity fluctuated between cohorts but reached a nadir in the seventh cohort at 0.92 ± 0.18 mCi/cm³ for I-125 and 4.33 ± 0.87 mCi/cm³ for Pd-103. **Conclusion:** Dosimetric quality parameters V100 and D90 improve with experience and approach a plateau after 20 – 30 patients.

WE-C-224C-03

Analysis of Technical Failures in 1000 Clinical Applications of Pulsed Dose Rate Brachytherapy

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Purpose: Investigation of safety and reliability of Pulsed Dose Rate brachytherapy within and outside office hours.
Method and Materials: More than 1000 patients were treated with two first generation (1996-2004) and three second generation (starting 2004) PDR afterloaders (Nucletron, The Netherlands). The most frequently treated tumorsites were breast, esophagus, gynecology, prostate and bladder. The number of pulses and the overall treatment time ranged from 4 pulses in 30 minutes for esophagus to 62 pulses in 135 hours for anal carcinoma. Apart from treatment-related parameters the type and frequency of technical failures, e.g. source obstruction, were registered for each treatment. From these data the fractions of disturbed pulses and treatments were determined for all tumor sites. Also the behavior of these fractions over time was studied. **Results:** Error frequency depended strongly on treated tumor site. For breast 149 out of 5936 pulses were disturbed (2.5%). For prostate the error fraction decreased from 16% in 11 patients to 11.7% after 49 patients. Gynecology scored well with only 28 disturbed pulses out of 2002 pulses given (1.4%). For breast the first error most often occurred in the first pulse. For prostate and bladder the first error occurred in a further stadium of treatment. By applying dummy checkwire runs, errors with the active source occurred only rarely. Our experience is that 98% of the patients received the intended dose correctly. Only in 2% of the treatments an adjustment of implant geometry or planned dose or a cancellation of part of the treatment was necessary. Of these 2% however, about half was caused by medical rather than technical reasons. No significant difference was seen between the first and second generation afterloader type.**Conclusion:** Errors do occur and are tumor site dependent. Our experience however shows that PDR can be safely applied, also outside office hours.

WE-C-224C-04

Correlated Sampling for Accelerating CT-Based Monte Carlo Dose Calculations for Brachytherapy Treatment Planning

Y Le*, D Todor, J Williamson, Virginia Commonwealth University, Richmond, VA

Purpose: To investigate the potential of correlated sampling variance reduction technique for accelerating CT-based Monte Carlo (MC) simulations for calculating 3D brachytherapy dose distributions.
Method and Materials: Correlated MC (CMC) simulations generate photon histories in the homogeneous geometry. By recomputing particle weights to account for non-water composition of the CT voxels and applicator and seed components, a second highly correlated set of histories is constructed, resulting in a lower variance estimate of the dose difference, $\Delta D=D_{het}-D_{hom}$ To evaluate the accuracy and efficiency of CMC, a clinical permanent prostate implant with 78 I-125 seeds was simulated using both CMC and UMC versions of our accelerated CT-based MC dose-computation code, PTRAN_CT for voxel sizes ranging from $1\times1\times1mm^3$ to $2\times2\times2mm^3$. Mean efficiency gains were estimated for regions with minimum doses greater than 20%, 50% and 90% of D_{90}, as well as different anatomical regions.
Results: Systematic differences between UMC and CMC PTRAN_CT were less than 0.4%. Efficiency gains ranged from 4.68 to 15.76 depending on the voxel size and region. CMC can achieve a 2% average precision with 2 mm cubic voxels in 23 seconds on a single P4 processor for voxels with doses > $50\%D_{90}$. Voxels with very low doses and/or large dose perturbations can experience efficiency losses. Because ΔD is a relatively smoothly varying quantity compared to D_{het}, CMC efficiency maybe enhanced using coarser voxel sizes than UMC for the same level of volume-averaging artifact. **Conclusion:** Correlated sampling MC can reduce CPU times by an additional 4-15 fold compared to accelerated uncorrelated MC. In practice, larger efficiency enhancements can be achieved because correlated sampling volume-averaging errors are smaller. MC-based brachytherapy treatment planning, requiring only a few seconds of CPU time, is achievable. (Supported by NIH-R01CA46640)

WE-C-224C-05

Tumor Brachytherapy Using Intratumoral Injection of Beta-Emitting Therapeutic Radionuclides Carried Within Nanoparticles

A Bao*, W Phillips, B Goins, R Otto, University of Texas Health Science Center at San Antonio, San Antonio, TX

The use of beta-emitting therapeutic radionuclides carried within nanoparticles for brachytherapy potentially offers significantl advantages over sealed sources. By using an active trapping technique, both therapeutic radionuclides, ^{186}Re and ^{188}Re, and diagnostic radionuclides, ^{99m}Tc, can be encapsulated in liposomes with high efficiency and high specific activity. ^{186}Re and ^{188}Re are beta emitters with appropriate ratio and energies of gamma emission which enable the imaging of in vivo distribution with a clinical gamma camera. The 90% absorbed dose deposit distances in soft tissue of beta ray from ^{186}Re and ^{188}Re are 1.8 mm and 4.2 mm respectively. To study the potential of using therapeutic radionuclides carried within liposomes for tumor brachytherapy, the intratumoral distribution and retention of ^{99m}Tc-liposomes in head and neck squamous cell carcinoma xenografts in nude rats were determined using imaging with a dedicated dual modality animal micro-SPECT / CT scanner. Using an intratumoral administration technique developed in our lab, the volume of administered radioactivity up to over 40 % of tumor volume can be delivered to tumor with a high local retention. The ^{99m}Tc-liposome studies show that about 40 % of injected activity remained in tumor with a very slow clearance. The cleared activity was not retained in the nearby critical

organ. Using pin-hole collimators with a spatial resolution of 1 mm, the ^{99m}Tc-activity had a broad diffusion throughout the tumor even though the injection was at one point within the tumor. This study has shown the potential of using beta-emitting therapeutic radionuclides carried within nanoparticles for tumor brachytherapy. The high intratumoral retention enables a high intratumoral radiation absorbed dose, while the penetration of beta-particles within only a few mm decreases the toxicity to nearby critical organs, and the intratumoral diffusion makes the intratumoral administration simpler and provides for a better intratumoral absorbed dose homogeneity.

WE-C-224C-06

Influence of Air Gap On Dosimetric Characteristics of Uniform and Composite Clinical 90Y Plaques for Dural Irradiation

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Purpose: A semi-cylindrical polycarbonate plaque incorporating a ^{90}Y foil has been developed and used to irradiate the dura in 14 spinal tumor patients. It has been hypothesized that inadequate fitting of the irradiator plaque to the dural surface could adversely affect the area of therapeutic dose delivery at the 90% level. A differentially-loaded composite treatment plaque has been designed to ameliorate potential air gap effects and maximize therapeutic dose delivery. **Method and Materials:** Two clinical plaque designs were evaluated, including a "standard" plaque containing a single foil of uniform activity, and a "composite" plaque containing a differentially-loaded ^{90}Y source created by placing a single activated square foil under an activated foil frame of the same outer dimensions in a titanium shell. Two dosimetry phantoms surrounded by a layer of radiochromic film (GafChromic HS) were constructed with radii approximating a perfect fit (matched to inner plaque radius) and a gap fit (80% of inner plaque radius) and irradiated with the two plaques. **Results:** Analysis of the irradiated film demonstrated that the effective treatment width to 90% of the plaque along the arc in the standard plaque is 65.8% when fitted and 58.1% in the presence of a gap; for the composite plaque, the corresponding treatment widths to 90% are 88.6% when fitted and 69.4% in the presence of a gap. Thus, in the presence of a gap the composite plaque delivers dose at the 90% level to a 19.6% greater arc width than the standard plaque with a gap, and 5.5% greater arc width than a perfectly fitted standard plaque. **Conclusion:** Differentially-loaded composite ^{90}Y plaques deliver therapeutic dose to a substantially larger treatment area than standard plaques currently used, and completely resolve treatment area to the 90% level potentially lost to inadequate fit with standard plaques.

WE-C-224C-07

Cervical Cancer Treatment: 3D Dose Determination Based On Low Energy and High Energy CT Image

S Hui*[1], B Gerbi[1], A Meigooni[2], P Higgins[1], Y Watanabe[1], M Ozer[1], S Awan[2], R Weaver[1], M Tomblyn[1], K Dusenbery[1], (1) Therapeutic Radiology, Univ Minnesota, Minneapolis, MN, (2) Univ Kentucky Medical Center, Lexington, KY

Purpose: To employ megavoltage CT (MVCT) to (a) generate an artifact-free image and compared with the kilovoltage CT (kVCT) image set in presence of Fletcher-Suit applicators, and (b) calculate precise three-dimensional anatomical dose distribution for low dose rate (LDR) treatment which can be combined with external treatment (based on kVCT) planning. **Method and Materials:** Consented patients undergoing radiotherapy treatment for cervical cancer were simulated using orthogonal films and kVCT for external treatment planning and low dose rate brachytherapy. Fletcher-Suit applicators with shielding were used for pretreatment image scans. Additionally, MVCT images were acquired using the Tomotherapy machine. These image sets (kVCT and MVCT) were fused in a Brachyvision planning system using a pixel registration method. MVCT images were then used for volumetric dose calculations using TG43 model. The MVCT image set and orthogonal film were then used to explore Monte Carlo-based 3D dose calculations. **Results:** Artifact-free images were obtained from MVCT scans using the Fletcher-Suit applicators. kVCT images were not useful for LDR treatment planning due to the presence of substantial artifacts. The MVCT image set was used in delineating the rectal and bladder tissue margins. However, soft tissue visualization was sub-optimal for clinical purposes. The MVCT image-based dose calculation generated three-dimensional dose distribution for rectum (max. dose of 56 cGy) and bladder (max. dose of 25 cGy) for single fraction prescribed dose of 600 cGy. Maximum rectum and bladder dose calculated using the MVCT image and orthogonal film based plan were very similar. **Conclusions:** We have showed that the artifact-free MVCT image offers accurate three-dimensional LDR treatment planning. In addition, the impact of dose heterogeneity will be calculated using image based Monte Carlo simulation technique. Ideally, truly individualized external beam and intracavitary radiotherapy may lead to higher cure rates and lower complication probabilities.

WE-C-224C-08

Pre-Clinical Evaluation of the New Xoft-AxxentTM Electronic Brachytherapy System

J Turian*, D Bernard, Z Hu, A Dickler, J Chu, Rush University Medical Center, Chicago, IL, USA

Purpose: To evaluate the preclinical functionality of the new Xoft-Axxent™ Electronic Brachytherapy System intended for partial breast irradiation treatment. Methods and Materials: The EB system consisting of: controller, X-ray source catheter, and the balloon applicator was tested for: graphical user interface functionality, X-ray generator parameters stability, beam output constancy, source position accuracy, timer accuracy, end effects, and dose distribution versus Ir-192 source. The safety features and the adequacy of the proposed shielding also have been tested. The system's log files which record the kVp, beam and filament currents were used to make inferences about the stability of the X-ray generator. Output constancy, timer accuracy, and end effects were measured using a PTW-34013 ion chamber and phantom. The dosimetric characteristics of the source obtained in a manner consistent with TG-43U protocol were entered into Plato™-TPS to compute the dose distributions. Source position verification was performed using manufacturer supplied procedures. Source step size accuracy was independently verified using external markers. The effect of transit time on dose distributions was simulated using low steps and dwell times for the transit positions. **Results:** The GUI was found to be functional for its intended purposes. The parameters of the X-ray generator were found to have variations of <0.5%(1σ). Output for single source was constant within 0.7% and for multiple sources 1.6% over the duration of the testing. Source position accuracy was <1.0mm. The timer error and linearity were -2.0s and 0.32%, respectively. Dose distributions show higher inhomogeneities towards the proximal end compared with Ir-192 distribution. All safety features were found to be operational.**Conclusion:** During preclinical evaluation the system was found to perform as expected. Minor revisions were proposed and should be integrated in the clinical system.

WE-C-224C-09

Calculation of the Dose Distribution Around a High Dose-Rate 192Ir Brachytherapy Source Via a Multi-Group Discrete Ordinates Method

K Gifford*[1], M Price[1], G Failla[2], T Wareing[2], J Horton[1], F Mourtada[1], (1) UT M.D. Anderson Cancer Center, Houston, TX, University of Texas MD Anderson Cancer Center, Houston, TX, (2) Transpire Inc., Gig Harbor, WA

Purpose: To calculate the dose distribution around a high dose-rate (HDR) ^{192}Ir brachytherapy source in water by a multi-group discrete ordinates code and compare with a benchmarked Monte Carlo calculated dose distribution. Methods and Materials: The multi-group discrete ordinates code, Attila™ version 5.0.2 (Transpire Inc., Gig Harbor, WA) was used to calculate the dose distribution around the Nucletron microSelectron HDR source (Nucletron B.V., Veenendaal, The Netherlands). MCNPX 2.4.k was used to benchmark the deterministic calculations. The source was constructed with Solidworks (Solidworks Corp., Concord, MA), a mechanical design software. The constructed geometry of the source, dose scoring plane and sphere were exported in Parasolid® file format so that it could be imported into Attila.

MCNPX 2.4.k was used to compute the Monte Carlo dose distribution. 50 million histories were simulated resulting in standard errors of the mean of less than 5% at a point 7 cm from the center of the source. The source geometry was identical to that of the Attila run except for minor differences in modeling the source due to limitations of the MCNPX code.

Dose rate matrices were exported from both codes and imported into an in-house data analysis software. This software overlaid the matrices and quantified the percent dose difference and distance-to-agreement for all points in the matrices. The number of points passing a 2%/2mm criterion were reported. **Results:** Attila calculated dose to within ±2% or 2mm for 99% of the points. The Attila calculations required approximately 38 minutes of CPU versus 568 minutes for MCNPX on the same CPU. **Conclusions:** The Attila multi-group discrete ordinates code accurately calculated the anisotropy from the microselectron HDR source. Attila accurately calculated dose in an efficient manner.

Therapy Symposium Room 224 A

Symposium in Memoriam of Peter Wootton: Secondary Cancer Risk for Emerging Radiation Treatments

WE-C-224A-01

Peter Wootton: A Personal and Professional Remembrance

I Kalet*, University of Washington, Seattle, WA

Peter Wootton was a legendary figure in the field of medical physics. He is known for early work on the foundations of dosimetry, for pioneering neutron therapy, for establishing regional medical physics services in the Pacific Northwest, and for many years leading the medical physics training program at the University of Washington. The American Association of Physicists in Medicine (AAPM) was incorporated in 1965, with Peter as a member of the initial Board of Directors, and signer of the organization's articles of incorporation. He also served a term as AAPM President in 1978. Under his leadership, in the early 1980's the University of Washington acquired, installed and operated what was then the most sophisticated neutron therapy facility in the entire world. This facility, still in service over 20 years later, continues to be state of the art. Peter was a superb teacher, and left a legacy of many M.S., Ph.D. and postdoctoral trainees, of which the author is one. His kind and wise spirit is greatly missed and remembered with awe and appreciation.

Educational Objectives:
1. Understand the role of Peter Wootton in the development of the field of medical physics

WE-C-224A-02

Radiation Induced Cancers in Treated Patients

H Suit*, Massachusetts General Hospital, Boston, MA

The increasing numbers of radiation treated patient surviving for long periods forces an assessment of their risk of radiation associated cancer.
Dose response relationships for cancer induction in the laboratory mice varies with strain, gender, tissue/organ of concern, observation period, dose fractionation and LET. For most experiments, risk increased with dose in an orderly manner. However, in some large experiments on mice and one on Macaca mullata, there was no evident increase risk of cancer at 1-2.Gy single dose WBI. These studies were life span and autopsy examinations.

Risk of death due radiation induced solid cancer among 86,611 survivors of the atom bomb explosions in 1945 [entered the study in 1950] increased throughout the observation period of 52 years. There have been 10,127 deaths due to solid cancer and of these, 479 [4.7%] have been attributed to the radiation exposure. The time distribution of these cancer deaths have been: 18%, 19.1%, 27.1% and 35.4 % for the periods 1950-67, 1968-77, 1978-87 and 1988-97. Namely, 35% of these radiation cancer deaths occurred at 42-52 years post irradiation.

Data from 14 large and long follow-up series of irradiated human patients demonstrate increased risk with dose for cancers of the stomach and pancreas; over the dose range 1-45 Gy. In contrast there was no evident increased risk of bladder or rectal cancer after doses of 1-60 Gy. For the studies on murine, canine, sub-human and human subjects there is not a constant relative risk for the different organs, *viz* probability of a radiation cancer for a specified dose varies with the organ.

Consideration will be given to the differential risk between photon [conformal and IMXT], proton [broad beam energy modulated and pencil beam scattered] and ^{12}C ion beams.

WE-C-224A-03

NCI Perspective On Clinical Trials for Emerging RT

J Deye*, National Cancer Institute, Bethesda, MD

The National Cancer Institute funds numerous clinical trials that employ radiation therapy either as the primary question in the trial or as standard of care adjuvant therapy that is only secondary to the primary agent. In any case it has been shown that the validity of the trial is strongly dependant upon the quality and reproducibility of the radiation administered. In all cases it is of paramount concern that the risks of the treatments be as quantified as possible so that the study design is valid and there can be a true informed consent. Toward those ends the NCI also funds efforts to ensure the correctness of the physical dosimetry (ie. Radiological Physics Center) and the comparability of advanced technical methods (ie. The Advanced Technology Consortium). This presentation will explain these cooperative agreements and highlight some of their accomplishments that impact upon the risks of using advanced radiotherapy methods in clinical trials.

WE-C-224A-04

Measurements of Secondary Radiation for Electron and Proton Accelerators

D Followill*, S Kry, M Salehpour, UT M.D. Anderson Cancer Center, Houston, TX

As new treatment modalities in Radiation Oncology such as Intensity Modulated Radiation Therapy (IMRT) and Proton Therapy (PT) become more widely used, improved target coverage and lower doses to surrounding normal tissues are achieved at the expense of higher out-of-field doses to distant normal tissues. These higher out-of- field normal tissue doses are the result of increased X ray leakage radiation from longer beam-on times associated with IMRT and neutron leakage radiation associated with high energy X ray beams (>10 MV) and protons. IMRT beam-on times can be 4-6 times that of conventional 3D treatments and neutrons produced by the high-energy X rays and protons striking a patient have a high relative biological effectiveness (RBE). Measurement of the increased X ray and neutron leakage radiation is crucial if one is to assess any additional risks to the patient that might result from the higher out-of-field radiation doses from these new treatment modalities. A variety of dosimeters, large volume ion chambers, diodes, survey meters, small volume ion chambers and thermoluminescent dosimeters (TLD), have been used to measure the X ray leakage in the treatment room and in the patient plane. TLD, because of its spatial resolution and ability to precisely measure low doses associated with leakage radiation, appears to be the preferable dosimeter. Neutrons are measured with bubble detectors, neutron meters utilizing a BF_3 proportional counter, ^{197}Au foil based activation either with a Bonner Sphere system/moderator or LiI dosimeters in Bonner Spheres. The gold activation technique has a calibration directly traceable to NIST and is the detector of choice for X ray produced neutrons. Due to the limited amount of neutron leakage measurement data around proton machines the ideal dosimeter has yet to be determined for this type of measurement. The measured dose-equivalent values in an anthropomorphic phantom for X ray leakage from an X ray accelerator decrease with increased distance from central axis (CAX) in the patient plane by a factor of 3 to 10, depending on the delivery mode and accelerator type. IMRT treatments on a Siemens machine results in higher dose-equivalents than the same energies on a Varian machine. Neutron measurements in the patient plane were approximately the same despite the distance from the CAX. Overall, the total dose-equivalent, X ray and neutron dose, decrease with distance from CAX with the Varian IMRT having the greatest decrease. Measured neutron dose-equivalents from proton therapy strongly depend on the delivery apparatus and decrease with distance from the nozzle. This lecture will provide an overview of the measurement techniques for X ray and neutron leakage radiation from both X ray and proton therapy machines and the resulting measured dose-equivalent values from which the risk of secondary cancers can be estimated.

Educational Objectives:

1. Understand the various techniques used to accurately measure X ray and neutron leakage radiation in the patient plane.
2. Understand the magnitude of the dose-equivalent in the patient plane from the various X ray accelerators and from proton therapy.

WE-C-224A-05

Patient Modeling and Organ Dose Calculations Using Monte Carlo Methods

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The risk for a patient to develop secondary cancers from non-target exposures can be assessed from the equivalent doses to various radiosensitive organs. To determine organ doses, a computational model or physical phantom that represents the whole patient anatomy must be used. Physical phantoms (such as the RANDO and ATOM phantoms) have tiny cavities on each of the tissue-equivalent slices for inserting TL and MOSFET dosimeters. When beam is delivered according to a patient's treatment plan, the dosimeters are processed to provide organ dose information. The experimental procedures can be time-consuming and expensive, especially when various patients and treatment plans are studies. Virtual patient models, on the other hand, can be combined with a Monte Carlo code to simulate the transport of radiation in the body. These models cover the entire body and typically contain a large number of defined organs. Coupled with a model of the accelerator, one can calculate detailed information about secondary dose distributions in the patient body. Whole-body models are classified into three types: 1) Stylized models that are based on surface equations, 2) Tomographic models that are derived from medical images, and 3) Hybrid equation-voxel models that describe organ boundaries using advanced primitives such as the NURBS for realtime deformation (4D simulations). To date, more than 20 tomographic models have been developed for radiation protection and nuclear medicine applications. An international consortium on computational human models (www.virtualphantoms.org) has been recently formed to promote research in this area. A team of researchers from Rensselaer, Vanderbilt, University of Florida, Massachusetts General Hospital and Johns Hopkins University is working on a project to standardize a library of age- and gender-specific models.

This lecture presents the current status of patient modeling and the application of various tools to study secondary doses from radiation treatment involving both photons and protons. Detailed information on the VIP-Man model developed from the Visible Human Project is presented. Segmentation of more than 80 organs, including the red bone marrow, and the implementation of the VIP-Man model into EGS, MCNP/X and GEANT4 are discussed. Finally, organ doses and effective doses for proton treatment plans using various adult and pediatric patient models are presented.

Educational Objectives of this symposium are:
1. Understanding new tools of Monte Carlo-based patient and accelerator modeling for secondary dose studies
2. Understanding the effective dose data for various modalities

Workshop Room 230 C
Ultrasound QC Workshop - I

WE-C-230C-01

Ultrasound QC Workshop

D Pfeiffer*[1], Z Lu*[2], H Miller*[3], R Spaulding*[4], W Moore*[5], (1) Boulder Community Foothills Hospital, Boulder, CO, (2) Columbia Presbyterian Medical Center, New York, NY, (3) Computerized Imaging Ref Systems, Inc, Norfolk, VA, (4) ATS Laboratories, Bridgeport, CT, (5) Sonora Medical Systems, Longmont, CO

Quality control testing of ultrasound scanners is gaining importance as the use of diagnostic ultrasound become more quantitative in nature and the systems and probes more complex in design. As evidenced by the rise in popularity of the American College of Radiology's ultrasound accreditation program, the need for comprehensive quality control programs is clear. This workshop is designed to provide attendees an opportunity to learn the impact of scanners and probes on various aspects of image quality and to refresh their skills in ultrasound QA/QC testing. The essential physics of ultrasound imaging and instrumentation will be reviewed. QA/QC testing procedures required by accreditation programs and advisory organizations will be presented. The impact of scanner and probe deficiencies on both B-mode and Doppler performance will be demonstrated. Tools for analyzing probes will also be demonstrated.

Finally, a discussion of quality control of prostate brachytherapy ultrasound will be presented. In the second half of the workshop, attendees will be given the opportunity to use the various tools and phantoms in a hands-on environment. Experienced instructors will be at the ultrasound scanners to guide the exercises.

Two identical sessions will be conducted, one in the morning and the second in the afternoon.

Educational Objectives:
1. To learn the effect of parameter settings and probes on various aspects of ultrasound imaging.
2. To observe the impact of system and probe deficiencies on ultrasound performance and image quality.
3. To become acquainted with various ultrasound QC phantoms and test tools and learn their proper use.

Imaging Scientific Session 330A
Small Animal Imaging

WE-D-330A-01

3D Optical Imaging of Tumor Microvasculature and Viable Cell Distribution

H Sakhalkar*, Y Wang, T Oliver, M Dewhirst, M Oldham, Duke University Medical Center, Durham, NC

Purpose: The ability to image 3D global structure (e.g. microvasculature) and function (e.g. gene expression) in whole unsectioned tumors, in high-resolution and with high-contrast, is of significant present interest in cancer research. We have developed novel optical imaging techniques capable of reconstructing the 3D distribution of absorbance or fluorescence-emitting sources in tumor tissue. Primary advantages include high spatial resolution and contrast, and ability to image a wide range of molecular probes. **Method and Materials:** Constitutive RFP expressing HCT116 (human colon carcinoma) xenograft tumors were implanted in hind legs of nude BALBC mice. The tumor microvasculature was dual-stained by *in vivo* tail vein injections of light attenuating isotonic ink and FITC lectin. The tumor was excised post-staining and subjected to a fluorescence-friendly clearing procedure to render it amenable for optical imaging. Quantitative images of microvascular density and viable-cell distribution were reconstructed using tomographic algorithms from a set of transmission and fluorescent projection images acquired at multiple angles using appropriate filters, focusing optics and a CCD camera.
Results: Co-registered, multimodal, high-resolution and high-contrast 3D reconstructions were achieved through large, (~1cm) whole mount, murine tumor samples. Quality assurance tests indicated encouraging accuracy of reconstructed attenuation coefficients and geometry. The 3D reconstructed slices were juxtaposed with histological slices of the same tumor to reveal striking correlation between viable-cell distribution and well-perfused regions. A fluorescence friendly clearing procedure was identified. **Conclusion:** We present a novel technique for multi-modality optical imaging of 3D microvasculature and/or viable cell distribution in tumor tissue with unprecedented image resolution and contrast. The technique has potential to image a wide variety of tumor and normal tissue structure and function. Of particular interest is the potential to analyze the effect of anti-angiogenic agents and radiation therapy on the response of the entire 3D tumor microvasculature network.

WE-D-330A-02

Optical-Computed-and Emmission Tomography: Applications in Cancer Research

M Oldham*, H Sakhalkar, T Oliver#, M Dewhirst, Dept Radiation Oncology, Duke University Medical Center, Durham , NC, # Dept Cell Biology

Purpose: This work explores the potential of optical-computed and emission-tomography (OCT/OET), when coupled with optical clearing techniques, for imaging aspects of biological structure and function for cancer research. OCT/OET are the optical analogues to x-ray-CT and SPECT respectively, and can yield high resolution high contrast 3D images of a variety of inherent or applied absorbing and fluorescing stains. **Materials and Methods** Several methods of staining tissue have been explored and applied to a range of tissue types. Xenograph tumor microvasculature was labeled with both passive absorbing stain and fluorescing active probes (e.g. lectin conjugated with FITC) by tail vein injection. Murine vasculature in major organs (lung, heart, brain) were stained with absorbing dye in a similar manner. OCT/OET imaging was performed using an in-house custom built scanner. Isotropic 3D transmision and emission data were reconstructed using tomographic algorithms from equiangularly spaced projection images. Results: Isotropic high resolution 3D image data of the xenograph tumor showed extensive peripheral microvasculature with the occasional larger vessels penetrating to the tumor core. High-quality 3D images of the lungs were achieved showing clear differences in perfusion between irradiated and unirradiated lung regions. Exquisite high contrast images were acquired of the vasculature and myocardial perfusion of the murine heart. **Conclusion** Primary advantages of OCT/OET include the preservation of tissue structure in 3D (tissue sectioning is not required), and the ability to acquire co-registered images of both structure (e.g.micro-vasculature) and function (e.g. perfusion, gene expression). Higher spatial resolution and higher contrast is achieved when compared with alternative modalities like micro-CT and micro-MRI. The techniques are versatile as imaging can be performed on a wide variety of absorbing and fluorescing stains.

WE-D-330A-03

PO2 Measurements in Animal Tumors Using An Image-Guided Robotic System

J Chang*[1], B Wen[1], P Kazanzides[2], P Zanzonico[1], R Finn[1], C Ling[1], (1) Memorial Sloan-Kettering Cancer Center, New York, NY, (2) The Johns Hopkins University, Baltimore, MD

Purpose: To develop and evaluate an image-guided robotic system for measuring pO_2 in animal tumors. **Method and Materials:** The robot consists of an X-Y horizontal platform holding the rodent bed, a dual-axis vertical arm for positioning the measurement probe and cannula, and fiducial markers for registering the coordinates of the imaging and robotic systems. Anesthesized and immobilized tumor-bearing rats are injected with the hypoxia tracer ^{18}F-FMISO and imaged in the rodent bed using an animal PET scanner. The reconstructed PET images are then uploaded into the robot computer, the rodent bed affixed to the X-Y platform, and the coordinates of the robot and PET registered. Based on the tumor hypoxia image displayed on the robot computer, motion of the robotic X-Y platform and vertical arm are coordinated to guide the positioning and percutaneous insertion of a probe (OxyLite-Optronix) to measure pO_2 at various locations in the tumor. The pO_2 readings (cps/voxel) are then compared to the respective image intensity of the measurement points. **Results:** The registration accuracy between the robot and image coordinate system was better than 0.2mm. Although the ^{18}F-FMISO in the bladder produced characteristic starburst artifacts in the surrounding, low-intensity regions, we successfully measured the pO_2 for three tracks. The ^{18}F-FMISO image voxel values were found to be inversely correlated with the intra-tumoral pO_2 of the three tracks with (Pearson product moment) correlation coefficients of -0.899, -0.420 and -0.857. The scatter plot of pO_2 vs. image intensity resembled a sigmoidal, rather than a linear relationship. **Conclusion:** PET-guided pO_2 measurement is feasible using this prototype image-guided robot system. To our knowledge, this is the first system of its kind - allowing direct point-by-point correlation of physiological probe measurements and image voxel values or, more generally, a physical action at a set of anatomic points identified on a preoperative image.

WE-D-330A-04

Serial Flat Panel Computed Tomography Quantification of Bleomycin-Induced Murine Lung Damage In Vivo

D Cavanaugh*[1], E Travis[2], R White[2], G Gladish[2], D Cody[2], (1) Texas Oncology, P.A., Fort Worth, TX, (2) UT M.D. Anderson Cancer Center, Houston, TX

Purpose: To compare methods of quantifying lung damage based on non-invasive flat-panel CT images with the standard method based on histologic section analysis. **Method and Materials:** Lung damage was induced in mice with bleomycin and damage progression followed with fpCT on days 10, 14, and 21 and with postmortem histological examination on day 21. Ten mice, five control and five treated, were scanned under breath hold with flat-panel CT (fpCT). Prior to scanning, a tail vein catheter was inserted for administration of IV contrast. The percent lung damage calculated from fpCT (PLD_{fpCT}) image data sets was compared to that obtained from sequential histological sections (PLD_H). **Results:** IV contrast was helpful in separating vessels from regions of lung damage. PLD_{fpCT} calculations were on average 2 times greater than PLD_H calculations. Linear trendlines were fit between PLD_H and PLD_{fpCT} to all data (n=10) and then to only the treated mice (n=5); the resultant R^2 values were 0.87 and 0.89, respectively. The fpCT scans allowed for observation of the progression of damage over time versus the single snapshot sampled with histology. Less damage was observed at day 14 than at either day 10 or day 21, which could be due to a transition from an acute inflammatory reaction to inflammation with formation of collagen. **Conclusion:** The quantification of lung damage based on fpCT images was strongly correlated to the conventional histological section analysis. Although the overall change in damage is consistent between histology and fpCT the magnitude of measured damage differs which may be explained by an inflammatory response throughout the lung which is not detected with histology. A potential strength of these longitudinal studies is the ability to follow individual animals over time to investigate biological affects such as a transition from acute to chronic damage patterns.

WE-D-330A-05

Voxel-Based MicroCT-MicroPET Image Registration for Molecular Imaging Study

E Schreibmann*, W Cai, X Chen, L Xing, Stanford University School of Medicine, Stanford, CA

Purpose: Registration of micro-PET and micro-CT images is important for the interpretation of multi-modality images. Here we develop a voxel-based image registration method to facilitate the co-registration of multi-modality imaging of small animals. **Method:** Rigid image registration (six degrees of freedom: three translational and three rotational parameters) was developed using an open-source ITK/VTK platform for coregistering micro-PET and micro-CT data. Modules importing/exporting DICOM data (binary mask files of contours and image sets) and the scanner specific proprietary microPET/CT/MRI data were also developed. Automated registration procedures based on the normal cross-correlation (NCC) metric and mutual information were implemented. To better "see" the bony landmarks in microPET, a strategy for enhancing the bone matrix uptake of radiotracer by adding a tracer amount of ^{18}F during the FDG-microPET imaging was investigated. The convergence behavior of the voxel-based registration algorithms was analyzed and the global convergence of the calculation was demonstrated. The accuracy of the developed registration algorithm was assessed by measurements using dual-modality external fiducial line sources incorporated into the mouse cradle. **Results:** A voxel-based registration technique has been established for *in vivo* molecular imaging study. Application of the technique to a number of mice micro-PET and micro-CT registrations indicated that an accuracy of better than 0.2 mm is achievable with the help of ^{18}F injection. Without lighting-up of the bony structures, however, we found that it is difficult to obtain a registration better than 1mm for regular FDG-microPET. Computationally, the setup based on the NCC metric performs better in comparison with the mutual information approach. **Conclusion:** A NCC metric coupled with the use of ^{18}F injection allowed us to obtain sub-millimeter accuracy in microPET-microCT registration of mice. The robust registration procedure should be valuable for routine molecular imaging application.

WE-D-330A-06

Dual Projection Imaging System for Small Animal Research

O Velazquez*, J Boone, K Yang, G Burkett, UC Davis Medical Center, Sacramento, CA

Purpose: The use of small mammals as models of human diseases has increased in the last several years. These models provide a valuable research tool to characterize these diseases and to evaluate new therapies. Dedicated imaging systems, with the resolution and sensitivity to allow in vivo studies in small animals, reduce the number of animals required for a given study and offer the possibility of serial studies in the same animal. A

dual two-dimensional imaging system has been developed to monitor tumor development in mice and other small animals. **Method and Materials:** This imaging system combines functional information gained from projection nuclear emission imaging with the anatomical context provided by an x-ray transmission image. The system captures a nuclear image in one side of a single computed radiography detector (CR plate) and then the plate is moved to acquire an x-ray image in the opposite side. The nuclear image is formed by using a parallel hole collimator. Four fiducial markers, that are visible in both images, are attached to the system. A transformation algorithm uses the information from the fiducial markers to align the images. The nuclear emission image is color coded and overlaid onto the gray-scale x-ray image. **Results:** For the assessment of the imaging system, a tissue-equivalent phantom was manufactured. Initial investigations used I-125. The spatial resolution, contrast, and detected scattered photon levels have been measured for both x-ray and nuclear imaging, and the sensitivity of the nuclear imaging system was also measured. **Conclusion:** The lower radiation levels, faster throughput, and lower cost of this imaging system would allow the evaluation of functional activity more frequently in serial studies. This imaging system would complement tomographic systems by allowing rapid pre-screening of animals when a complete 3D volume data set is not necessary.

WE-D-330A-07

The Small-Animal Radiation Research Platform (SARRP): Focused Pencil Beam Dosimetry

H Deng[1]*, C Kennedy[1], E Armour[1], T McNutt[1], E Tryggestad[1], E Ford[1], I Iordachita[2], P Kazanzides[2], J Huang[1], J Wong[1] (1) Dept. of Radiation Oncology and Molecular Radiation Sciences, Johns Hopkins Medicine, Baltimore, MD. (2) Center for Computer-Integrated Surgical Systems and Technology, Johns Hopkins University, Baltimore, MD.

Purpose: A small animal radiation platform equipped with on-board cone-beam CT and conformal irradiation capabilities is being constructed for translational research. This work reports on the dosimetric characteristics of the x-ray lens subsystem used for high-resolution dose delivery. **Method and Materials:** A constant voltage 225 kVp x-ray beam from a 0.4 mm focal spot is shaped and directed to enter a 1.5 cm long, 2 cm diameter cylindrical multi-layer graphite x-ray lens placed 16 cm downstream from the source. The lens emits a converging circular beam of 40-80 keV x-rays which forms a narrow cylindrical beam centered at 33.5 cm downstream with a length of approximately 5 cm in air. The pencil beam disperses further downstream. We measured dosimetry of the beam in water equivalent plastic using Gaf-chromic EBT films (<0.1 mm pixel size) over a SSD range of 30 to 33.5 cm in steps of 5 mm. For each SSD, 36 films were orientated orthogonal to the beam and at every 2 mm between slabs in the depth direction. We established the optical density-to-dose calibration with a 6 MV beam. **Results:** The beam has a highly peaked cross-beam profile with a full width half maximum of about 1.5 mm in the focal zone. Irregular cylindrical symmetry is present due to imperfect lens construction. Dose deposition was defined as the average value over a circular area with a diameter of 1.5mm from the beam axis. Surface dose rates are 230 – 160 cGy/min over the 3.5 cm range of SSDs. The percent depth dose is approximately 34% at 2 cm depth for a beam at 33.5 cm SSD. **Conclusion:** Highly localized dose can be delivered with the focused pencil beam. Work is on-going to improve dose uniformity by lens rotation, and to develop a pencil beam algorithm for planning purposes.

WE-D-330A-08

The Small-Animal Radiation Research Platform (SARRP): Commissioning a 225 KVp "small-Field" X-Ray Source for Monte Carlo-Based Treatment Planning

E Tryggestad[1]*, E Armour[1], H Deng[1], E Ford[1], J Huang[1], I Iordachita[2], P Kazanzides[2], C Kennedy[1], T McNutt[1], F Verhaegen, [3], J Wong[1] (1) Dept. of Radiation Oncology and Molecular Radiation Sciences, Johns Hopkins Medicine, Baltimore, MD. (2) Center for Computer-Integrated Surgical Systems and Technology, Johns Hopkins University, Baltimore, MD. (3) Medical Physics Unit, Montreal General Hospital, McGill University, Montreal, CA

Purpose: To characterize the dosimetry of a small-field 225 kVp x-ray source and demonstrate the feasibility of the Pinnacle *Monte Carlo Dose Computation* engine (v7.9t alpha release) for treatment planning in the context of small-animal radiation therapy. **Method and Materials:** The 225 kVp therapeutic x-rays for the Small-Animal Radiation Research Platform (SARRP) are produced by a GE 225 x-ray tube (spot size 3 mm; Al filtration 4 mm). A simple small-field collimation system was constructed; for commissioning purposes we machined a set of brass cutouts which define field sizes of 3x3, 5x5, 10x10, 30x30 and 60x60 mm^2 at the nominal SARRP source-to-axis distance of 33.5 cm. The x-ray beams were characterized by irradiating Gafchromic EBT film in water. The film plane was oriented parallel to the central beam axis (z); measurements were made in the x-z and y-z planes for all field sizes. Dosimetric data were extracted from the films using a commercial flat-bed document scanner. Profiles and percent depth-dose (PDD) curves for depths from 0-9 cm (SSD = 33.5 cm) were imported into our research planning software for comparison with simulated data. **Results:** Preliminary simulated profiles for the 60x60 mm^2 cutout deviate, on average, by 1.7% and 2.8% in the high-dose region (90% or greater) for depths of 0.5 and 3 cm, respectively. Average PDD discrepancies for depths from 0-3 cm and 3-6 cm are 4.3% and 18.4% for the 60x60 mm^2 cutout, respectively, and 6.6% and 29.2% for the 5x5 mm^2 cutout. **Conclusion:** These encouraging results identify the feasibility of using this planning system. Pinnacle supports the finer resolution required for modeling the small fields. Future development will involve incorporation of a measured photon energy spectrum. For purposes of comparison and validation, we will also incorporate an independently-generated photon phase-space file for the simulated x-rays.

WE-D-330A-09

An Image-Guided Irradiator for Pre-Clinical Radiation Therapy Studies

D Jaffray*, D Moseley, J Chow, S Kim, S Ansell, G Wilson, C Chiarot, Princess Margaret Hospital/Ontario Cancer Institute, Toronto, ON, CA

Purpose: The development of IMRT has increased the community's reliance upon dose-volume constraints for normal tissue avoidance and the development of SBRT has increased the consideration of alternate fraction schedules. The lack of clinical data for supporting these changes in practice places additional pressure on the development of realistic animal models for fractionation and normal tissue dose-volume studies. In support of these efforts, the construction of an image-guided radiation therapy unit for small animals has been initiated. The current status of this development and its design elements are described. **Method and Materials:** The system is comprised of a decommissioned radiation therapy simulator (Nucletron – Simulix) adapted to support a flat-panel detector (Perkin Elmer, RID1640) and a 225kVp x-ray tube (GE Siefert 225, f.s.=0.4-3mm). The pulsed radiographic exposures (200-600) collected over 360 degrees are reconstructed using a filtered back-projection cone-beam CT method. Soft-tissue visibility and geometric targeting of the system components have been assessed. EGSnrc Monte Carlo simulations were performed to assist in the design of the optimal treatment geometry for rodent and rabbit models. The simulations for 225 kVp x-rays (1 cm diam circular field size) have been considered to achieve high dose rate, small penumbra, and acceptable clearance during arc-based delivery. **Results:** The cone-beam CT imaging system generates soft-tissue images of rodents with sub-mm resolution. Monte Carlo results demonstrate penumbral performance (d90-50) of the system with a 3mm focal spot and reduced collimator-object distance will be under 1mm. A radial dose gradient can be established from 360 degree arc approach (9%/mm from D90-d50) for small field sizes. **Conclusion:** The development of a cone-beam CT guided radiation therapy unit with sub-mm resolution and high 3D dose gradients is progressing. Initial simulations and imaging system development suggests that precisely located spherical dose distributions can be delivered with such a system.

Imaging Symposium — Room 330 D

DR in Practice

WE-D-330D-01

Determination and Optimization of DR Receptor Dose

R VanMetter*, Eastman Kodak Company, Washington, DC

Unlike conventional radiographic receptors (screen-film), digital systems do not generally have a fixed speed, but respond over a wide range of

receptor dose. Therefore, specifying and monitoring receptor dose is an important component of quality assurance for digital radiography. Digital radiographs are currently characterized in terms of a variety of incompatible, vendor specific speed or dose metrics, which make it difficult for users to monitor receptor dose or to inter-compare receptor dose from different systems. The lack of a universal vendor-independent measure of receptor dose has prompted the formation of AAPM Task Group 116, which is currently working to "Standardize an Image Receptor Dose Index for Digital Radiography".

This talk will review the currently available vendor-specific measures of receptor dose, describe and illustrate a set of desirable attributes that should characterize a universal receptor dose metric, and explore some of the pitfalls and opportunities that having a universal metric afford. Digital radiography offers a substantial opportunity to optimize and standardize radiographic practice well beyond what could be done with conventional imaging. These along with some of the pitfalls that must be avoided will be illustrated by comparing several specific proposals for measuring receptor dose applied to a large set of clinical images for which body part, projection, thickness, technique factors (kV, mAs and SID) were documented. These alternative approaches will be compared in terms of their conformance to the desirable attributes developed at the outset.

A well-designed universal measure of receptor dose enables a vision for digital radiography that encompasses improved patient care through optimized and consistent image quality and dose. The concepts reviewed in this presentation are expected to influence the development of international standards for receptor dose anticipated within the next few years.

Research sponsored by the Eastman Kodak Company.

Learning Objectives:
1. Understand the translation of screen-film speed and dose concepts into a digital environment.
2. Understand the relationship among the many measures of dose, including the vendor specific measures of receptor dose.
3. Appreciate the need for and the desirable attributes of a universal vendor-independent measure of receptor dose.
4. Understanding the use and interpretation of receptor dose in clinical practice.

WE-D-330D-02

Non-Ideal Behavior of DR Systems

C Willis*, UT MD Anderson Cancer Center, Houston, TX

Ideally, we would like for clinical digital radiography (DR) systems to produce faithful reproductions of radiographic projections, acquired at optimum gain, and rendered appropriately for diagnostic interpretation. We also expect uniform performance from identical DR systems. We would like DR systems to maintain their optimum performance indefinitely, or at least to alert us when their performance falls below reasonable limits. We expect DR systems to be user-friendly, to accommodate operator Quality Control (QC) activities, and to enable the operator to correct errors without the need for a repeated exposure. In reality, all DR systems fall short of these ideal expectations. Awareness of causes and corrective actions for non-ideal behavior is important for Medical Physicists in order to assist clinical practice with DR.

The talk will consider the effects of discrete detector elements, gain compensation maps, and "ghost" images on acquisition of the radiographic projection. Variation in gain and SNR with exposure will be discussed. Sources of interferences with image segmentation will be described including hardware, shielding, and the challenge of large and small patients. The influence of operator technical errors will be explored. The value of automated quality control self-tests in assessing and maintaining optimum performance will be examined. The ability of the operator to intervene in the event of a sub-standard image will be considered. Positive and negative aspects of operator modification will be mentioned. Discrepancies between display functions at the acquisition station and at the physician's diagnostic display will be discussed.

Learning Objectives:
1. Appreciate the technological limitations on ideal behavior by DR systems.
2. Understand the clinical manifestations of non-ideal DR behavior.
3. Identify actions that can reveal or correct non-ideal DR behavior.

WE-D-330D-03

DR in Practice - Mammography

R Pizzutiello*, Upstate Medical Physics, Victor, NY

Purpose: To explore the impact of DR mammography on the practice of clinical medical physics. Historical and new methods for providing scheduled and unscheduled mammography physics services for facilities using DR mammography will be presented. **Method and Materials:** Clinical medical physics services provided to DR mammography facilities from various manufacturers will be presented. Quality control activities approved by FDA for each individual manufacturer will be compared. The status of a proposed "Alternative Standard" to allow for a more uniform approach to medical physics mammography services will be reviewed. Case studies will be presented demonstrating methods and cost considerations for providing medical physics services under the "minimum standard" (prescribed by MQSA regulations) and "best practices" model. **Results:** Medical physics services provided in the "minimum standard" and "best practices" model have implications for the quality and cost of mammography physics services. **Conclusion:** Medical physics services may be provided in a professional and valuable manner, using combinations of the minimum standard of practice and the "best practices" model. The professional medical physicist should consider multiple parameters when determining the appropriate model under which to deliver services.

WE-D-330D-03

DR in Practice - Mammography

R Pizzutiello*, Upstate Medical Physics, Victor, NY

Purpose: To explore the impact of DR mammography on the practice of clinical medical physics. Historical and new methods for providing scheduled and unscheduled mammography physics services for facilities using DR mammography will be presented. **Method and Materials:** Clinical medical physics services provided to DR mammography facilities from various manufacturers will be presented. Quality control activities approved by FDA for each individual manufacturer will be compared. The status of a proposed "Alternative Standard" to allow for a more uniform approach to medical physics mammography services will be reviewed. Case studies will be presented demonstrating methods and cost considerations for providing medical physics services under the "minimum standard" (prescribed by MQSA regulations) and "best practices" model. **Results:** Medical physics services provided in the "minimum standard" and "best practices" model have implications for the quality and cost of mammography physics services. **Conclusion:** Medical physics services may be provided in a professional and valuable manner, using combinations of the minimum standard of practice and the "best practices" model. The professional medical physicist should consider multiple parameters when determining the appropriate model under which to deliver services.

Joint Imaging/Therapy Scientific Session — Valencia B

Molecular Imaging & Image Registration / Fusion

WE-D-ValB-01

Effects of PET Reconstruction Parameters On the Delineation of Heterogeneous Target Volumes

D Barbee*, R Flynn, C Jaskowiak, R Jeraj, University of Wisconsin, Madison, WI

Purpose As emerging radiotherapy techniques incorporate biological targeting of sub-tumor volumes, steps must be taken to ensure the validity of the assumed substructures. This study measures the effects of PET image reconstruction on heterogeneous target definitions both *in vivo* and in a phantom. **Method and Materials:** A known heterogeneous phantom

composed of Y-86 and Ge-68 spheres with an F-18 background altering signal-to-background ratios tested the accuracy of reconstructions using ordered subset expectation maximization (OSEM) with varying numbers of iterations and filtered backprojection (FBP) with Hanning, Shepp-Logan, and ramp filters. *In vivo* measurements used heterogeneously proliferating tumor images obtained from a canine tumor imaged using [F-18]FLT at three stages of treatment using the same reconstruction methods. Difference images and standard deviations were used to assess the reconstruction differences. A three-dimensional form of the Moran I(d) spatial statistic was used to assess global heterogeneity at various correlation distances.
Results: Absolute difference images from FBP and 2 iteration OSEM reconstructions showed internal tumor voxel clusters deviating by more than 10% of the maximum SUV of the reference image (OSEM20) and relative voxel values varying by as much as 40% in tumor periphery. Image differences in OSEM reconstructions significantly decreased after 10 iterations, accompanied by decreases in the standard deviation of differences and slight increases in heterogeneity as global I(d) values decreased. FBP reconstructions both underestimated (Hanning, Shepp-Logan) and overestimated (ramp) global heterogeneity I(d) relative to reference values, but large standard deviations of absolute difference indicated images compared poorly to the reference. **Conclusion:** Tumor heterogeneity obtained through PET may vary by at least 10% internally with larger variability at the periphery, greatly affecting both tumor volume delineation and internal heterogeneity. Prescriptions for dose painting based on proliferation measures can vary widely with the reconstruction algorithm.

WE-D-ValB-02

Thresholding of PET Target Volumes for Treatment Planning and Response Monitoring: Measurement and Modelling Approaches

H Keller*, S Breen, D Vines, D Jaffray, Princess Margaret Hospital, Toronto, ON, CA

Purpose: To describe a method to determine the thresholds of different sized objects in PET images for the purpose of target segmentation for radiotherapy treatment planning and response monitoring and compare the measurements to a modelling approach using point spread functions. **Method and Materials:** PET images of the IEC image quality phantom containing 6 spheres of different size containing a known activity concentration of an [F-18] solution were repeatedly imaged at different times in both 2D and 3D PET acquisition modes. Nominal thresholds were found for each sphere and plotted against the mean uptake values in each sphere. The point spread function (PSF) of the PET scanner was measured by imaging a 1 l drop of high activity concentration. The full-width-at-half-maximum (FWHM) of these PSFs was then used to generate simulated PET images by convolving a binary mask of the 6 spheres with the PSF in 3 dimensions. **Results:** Nominal thresholds and the mean uptake scale linearly with activity concentration for a given sphere size. The slope of these threshold-uptake lines are larger for smaller spheres. The deviation from the slope 0.5 indicates the degree of partial volume effect or non-uniform uptake in the target. Once these lines are quantified the actual threshold for a target of unknown size (approximately spherical in shape) can be found by an iterative procedure. The FWHM of the measured PSFs depends on acquisition mode and PET reconstruction parameters. For the 3D mode, the PSF model excellently predicts the nominal thresholds for all sphere sizes, but not for the 2D mode. **Conclusion:** Segmentation of targets for treatment response monitoring requires an adaptation of the thresholds if the target size is shrinking. The PSF has the potential to be used for pre-processing the PET image before segmentation.

WE-D-ValB-03

Application of a Gaussian Mixture Model for the Segmentation of Lung Tumors in Positron Emission Tomography

M Aristophanous*, M Martel, B Penney, C Pelizzari, The University of Chicago, Chicago, IL

Purpose: FDG-PET is increasingly used in the gross tumor volume (GTV) definition of lung cancer patients undergoing radiotherapy. There is currently no reliable technique for segmenting GTV using PET, mainly due to varying background levels of the mediastinal blood pool and normal lung. We have developed a semi-automatic segmentation technique based on Gaussian Mixture Models (GMM). **Method and Materials:** The PET image data (voxel intensities) are assumed to be realizations of random variables (RVs) whose density functions can be represented as a mixture of Gaussian density functions, each weighted by their mixing proportion. Each density function represents a level of activity concentration, called a "class". Four classes are defined to describe the data; Background-Low, Background-High, Target, "Mixing". We assume "Mixing" is a mixture of the other three classes, which are considered to represent Single Activity levels (SA). User interaction is limited to initial selection of an over-sized region around the tumor and initialization of model parameters. Expectation Maximization is used to calculate Maximum Likelihood estimates of the parameters (mean, variance, mixing proportions of each class) of the model. The results are then used to segment the image into the three SA classes. The algorithm was tested on the NEMA phantom with varying target/background ratios and ten patient studies. **Results:** The GMM segmentation of the NEMA phantom spheres was comparable to thresholding at 40% of the maximum. For inhomogeneous tumors, segmentation with GMM was far superior to thresholding. For homogenous tumors GMM was as good or better than thresholding.**Conclusion:** A segmentation technique based on Mixture Models was applied for the first time on PET images, with encouraging initial results. Segmentation obtained with the GMM model is based on statistical analysis of the images, making it more reliable than current thresholding methods. Additional studies will assess its accuracy.

WE-D-ValB-04

A Framework for Multimodal Thresholding, Target Delineation and Therapy Monitoring

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Purpose: To develop a framework for the integration of multimodal and multidimensional treatment planning data and to evaluate the potential of the framework through application to several clinical problems in radiotherapy. There is a lack of tools to assist in the integration of multimodal imagery and applying this towards radiotherapy target identification. Fusion of multimodal imagery allows the characterization of points in space in terms of the individual signal intensities that define the co-registered voxels of the multimodal images. This parameterization permits alternative visualizations of the fused images, and can be exploited in order to develop novel treatment planning tools. An alternative visualization termed “feature space” forms the basis of a flexible framework for the integration of multimodal data, and the utility of this framework is illustrated. **Method and Materials:** The framework was applied to the analysis of multimodal images of patients with Non-Hodgkin’s lymphoma and nasopharyngeal carcinoma. Images were registered and displayed as joint intensity distributions. Voxels within regions-of-interest in the component images were identified in the joint distributions. Conversely, voxels in the joint distributions can be selected and identified in the component images. Features of interest in the images that share similar parameters will cluster in the intensity distributions. Clusters of high density denote significant features. Image voxels are assigned membership to these features and are classified accordingly. **Results:** The framework was applied to several clinical data sets, and shows potential as a multimodal thresholding technique, a tool to assist in target delineation and in the development of novel metrics for therapy monitoring. **Conclusions:** A framework has been developed for the integration of multimodal data and has been applied to target delineation and therapy monitoring. The ability to accurately delineate the target and monitor treatment response is an essential component in the trend towards patient-specific image-guided adaptive interventions.

WE-D-ValB-05

Sinogram-Based Respiratory Gating for 5D PET

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Purpose: PET/CT for tumor delineation is degraded when the tumor lies in a region of the body moved by breathing motion. It was recently determined that breathing motion is characterized by the depth and rate of breathing. This approach (“5D model”) has been shown to accurately reproduce even very irregular breathing motion. We have developed the model for use in PET image reconstruction for the removal of breathing

motion artifacts. **Methods and Materials:** The PET acquisition is gated using the tidal volume and airflow and binned according to a user-specified breathing phase. One of the main considerations with researching this process is the ability to reconstruct PET images. For modern PET scanners, the manufacturer uses sophisticated image reconstruction that cannot be accurately reproduced in the lab, so manipulation of the sinogram data file with subsequent reconstruction by the manufacturer would be ideal. We tested this critical function by acquiring a cardiac-gated sinogram data file from a PET/CT manufacturer (Philips, Cleveland OH). The sinogram-header file was copied byte-by-byte to a new file and the remaining file examined to determine the relative cardiac phase between timing data. The sinogram file was rewritten with the events in the user-selected phase and sent to the commercial image reconstructor. The subsequent images compared against the commercial gating software produced images. **Results:** The images were nearly identical and showed we had clearly and accurately gated the PET sinogram data. Because of a memory limitation, our gated sinogram data had 1/3 the number of events of the original sinogram file. **Conclusions:** We have shown that the most complex part of studying 5D PET gating can be conducted using the commercial software package. This allows us to continue working on the 5D PET process and extend to dynamic phantom studies.
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WE-D-ValB-06

Correlation Score Based Respiratory Gating for Lung Cancer Radiotherapy Without Implanted Fiducial Markers
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Purpose: To perform reliable respiratory-gated treatment of lung cancer using fluoroscopy without implanted fiducial markers. **Method and Materials:** Six methods are evaluated for use in respiratory-gated treatment of lung cancer without implanted markers. Using a fluoroscopic simulation session as training data, correlation templates are built that represent the appearance of the lung at end-of-exhale (EOE) phase. First, all the images at EOE phase are averaged to generate a single template. Next, four methods are investigated to combine multiple correlation scores from templates. Finally, clustering is used to reduce a large number of EOE templates into a few representative ones. Each of these methods is evaluated against ground truth gating data as determined by a physician. Six patient data sets are evaluated. In each case, the template matching method is scored, and gated treatments are simulated at 35 percent duty cycle. **Results:**
Error rates using all methods were computed relative to the physicians marked locations. Depending on the patient and method, the accuracy of the resulting gating signal varied between 84 to 100 percent, with a false alarm rate of between 0 and 7 percent. The clustering approach was the most stable method, with gating accuracy of greater than 90 percent, and false alarm rates of less than 4 percent, for six patients. **Conclusion:**
This work demonstrates that template matching methods might be useful for respiratory gating in lung cancer treatment. Among the methods tested, the clustering method was most accurate, because it reduces the redundant information in the image sequence.

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WE-D-ValB-07

Patient Setup Based On Lung Tumor Mass for Gated Radiotherapy
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Purpose: To develop a lung cancer patient setup technique for gated radiotherapy based on the direct image registration of lung tumor mass. **Method and Materials:** We develop a tumor mass based patient setup technique for gated radiotherapy that matches the lung tumor of the radiographic image to the DRR image. For each patient, AP and lateral DRRs at exhale are generated from the corresponding 4DCT data with the projected GTV outer contour. During patient setup, AP and lateral radiographs are acquired at exhale using an on-board x-ray imaging system. First, an image registration algorithm is applied to match the regions of interest around the tumor mass in both radiographic and DRR image. Second, an interactive registration procedure, which uses a computer mouse to drag the GTV contour in the radiographic image to its correct position, is applied to verify and/or correct the automatic registration results. **Results:** We tested the various existing image registration algorithms and found that maximizing mutual information performs best for lung tumor registrations. Excellent matches can generally be made, and if nuanced adjustments are needed for a particular patient, they can be accomplished through interactive registration. **Conclusion:** Automatic registration of lung tumor mass in radiographic image to DRR is feasible for most of patients to provide precise patient setup based on tumor mass, rather than skin markers or bony structures. Interactive registration is needed to provide human verification and correction. **Conflict of Interest:** Research is partially sponsored by an NCI grant (1 R21 CA110177 A 01A1).

WE-D-ValB-08

4D Dose Calculation Using 3D Elastic Dose Registration in Lung IMRT
J Wu*, D Nazareth, C Castro-Pareja, P Lei, R Shekhar, W D'Souza, University of Maryland School of Medicine, Baltimore, MD

Purpose: To develop an elastic registration algorithm that will register dose distributions computed on each 3D data set of a 4D CT images set. Methods and Materials: The goal of image registration is to find the best matching point pair of two images. The coordinates between the two points were related by a transformation field. Mean-squared intensity difference was used for similarity measurement. The optimal transformation was found by maximizing similarity.
Eight 3D CT image set were obtained by phase based sorting. CT image corresponding to end-exhale was selected as reference image. The remaining images were registered to the reference image.
We performed an IMRT planning on the reference image. The prescribed dose was 66 Gy with 2 Gy/fraction. The plan parameters were superimposed on the images corresponding to the remaining phases. A convolution algorithm was used to calculate the resulting dose distributions. After that each 3D dose was transformed to the reference phase by applying the resultant transformation fields. Equally weighted superposition of these transformed dose was calculated. DVH of the planned and registered doses were compared. **Results:** Image registration improved the matching of anatomical features. RMS error of the intensity difference between the reference and floating images reduced from 81.2 before registration to 70.6 after registration. When compared the planned and registered doses, 95.4% of the tumor will receive the prescribed dose without motion compensation. However, after registration only 81.8% of the tumor received the prescribed dose. The heart and left lung had a less than 1% mean dose difference between the planned and registered doses. The right lung had a 5.8% mean dose difference. **Conclusions:** Our algorithm has the potential for automatic registration. It further helped us determine the difference between the planned and true dose distribution.

WE-D-ValB-09

Deformable Image Registration with Auto-Mapped Control Volumes
S Kamath*, E Schreibmann, L Xing, Stanford Univ School of Medicine, Stanford, CA

Purpose: Conventional deformable registration treats all image volume equally and the calculations are “brute-force” in nature. In reality, some regions can be mapped between the moving and fixed images with high confidence. In this work we investigate a strategy of using *a priori* knowledge about the system to reduce the dimensionality of the deformable image registration. **Method and Materials:** We propose a two-stage deformable image registration algorithm that incorporates prior knowledge into the system through auto-mapping of control volumes. In the first stage, a set of control volumes is selected on the fixed image. Each control volume is mapped on to the moving image using a rigid transformation. Control volumes are placed on distinct features for robust auto-mapping. In the second stage, a BSpline grid is defined over the moving image. For each control volume, the nearest point on the grid is located based on the Euclidean distance. An upper bound that is dependent on the displacement of the control volume in the auto-mapping is imposed on the corresponding grid point. The BSpline deformable transformation is determined for registration of the two images subject to the bounds on the displacements of the grid points as described. The utility of the new method is demonstrated by clinical case studies. **Results:** The algorithm was applied to register phases of 4D-CT images for mapping lung and liver deformations. Experimental results show that the algorithm is fast, robust and practical

with a registration accuracy of ~2mm. **Conclusions:** We have developed a deformable registration mechanism that incorporates *a priori* system knowledge to improve the performance of registration. The algorithm is based on the BSpline deformable transform with displacement constraints based on auto-mapped control volumes. The algorithm has been found to be practical for registration of phases of 4D-CT images of lung and liver.

Joint Imaging/Therapy Symposium Valencia A

Joint Imaging-Therapy Symposium in Memoriam of Edward Webster: In-Room Non-Tomographic Guidance of Radiotherapy

WE-D-ValA-01

Memorial for Edward Webster

R Gorson*, Columbia, SC

Edward (Ted) W. Webster, Ph.D., 5th AAPM President, 12th Coolidge Awardee, and 16th Taylor Lecturer passed away on 17 December 2005 after a brilliant career of over a half century in medical physics. Besides making many contributions to the physics of diagnostic radiology and to the studies of the biological effects of low doses of radiation, Ted was a superb scholar and renown lecturer who greatly influenced the careers of many hundreds of radiologists and physicists.

WE-D-ValA-02

Radiographic & Fluoroscopic Guidance of Respiratory Sites

S Jiang*, Massachusetts General Hospital and Harvard Medical School, Boston, MA

Respiratory motion is both intra- and inter-fraction. For lung and liver tumors, the magnitude of inter-fraction motion is often comparable with that of intra-fraction motion. The position of a moving organ during one fraction can be decomposed into the average position and the instant position relative to the average position. Here we introduce a concept called daily home position of a moving organ, which is often the mean position averaged over the treatment fraction. However, it may be a position corresponding to a particular breathing phase. For example, if the treatment is gated at the exhale phase, it makes sense to define the tumor home position as the exhale position.

For lung and liver tumors, image guided setup means the detection of daily tumor home position and the alignment of this position to the reference home position. If tomographic guidance is used to setup lung or liver cancer patients, either using CT on-rail or on board cone beam CT, the accurate daily tumor home position may be generated from a 4D scan, but not a 3D scan without patient breath holding. Daily breath hold 3D scan is not practical because it is difficult for patients with poor pulmonary function. For daily 4D scan, among others, how to reduce the potentially large amount of radiation dose and how to efficiently manage large amount of image data might be two major problems for its application to patient setup. For livers with implanted fiducial markers, it is easy to detect the marker positions, thus the daily tumor home position, either radiographically or fluoroscopically, using a gantry-mounted or a room-mounted x-ray imaging system. For lung patients, we usually do not have any fiducial markers implanted in the lung, due to the concern about the risk of pneumothorax. Radiographic or fluoroscopic detection of lung tumor mass is not a trivial task. For some lung tumors, their projections in the images may be identified using current imaging techniques. For others, more advanced imaging techniques are required and this is still an on-going research topic.

As to image guided delivery, the requirement on the amount of tumor location information is different, depending on the delivery technique. For beam tracking, the instant tumor position should be tracked. For gating, we only need to make sure the tumor home position is maintained within the gating window during the treatment fraction. It is difficult, if not impossible, to have tomographic guided delivery. Fluoroscopic tracking of implanted fiducial markers is relatively easy. However, we still need to pay attention to various practical issues, such as the changes in marker shape in projection images due to maker rotation for none-spherical markers, occlusion by and confusion with bony structure and air bubbles, tracking closely located multiple markers, poor image quality with MV beam interference, etc. Fluoroscopic tracking of lung tumor mass without implanted fiducial markers is challenging. Some promising results have been seen recently. However, a lot more research is needed before those techniques can be clinically useful.

WE-D-ValA-03

Radiofrequency-Based Localization

T Willoughby*,
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Intra-fraction and inter-fraction motion have continued to be areas where much study is needed in order to accurately target areas for radiation treatment. Many modalities have been explored that allow the user to evaluate the patient location from day to day, as well as during a single treatment session. Most of these applications are image-related, including, both planar X-rays (either KV or MV), CT scanning (KV or MV), as well as ultrasound. Each imaging modality has its unique set of issues including, time involvement, radiation exposure, and subjectivity in registration).

Non-tomographic methods to deal with inter and intra-fraction motion have been explored. For many years optical tacking with the use of infrared cameras have been used for radiosurgery and radiotherapy. These systems will be discussed in brief, but they are limited to external information and offer little information on internal organ motion. They are important in many applications related to target motion in that they can be used to create a model between the patient surface and internal motion. They can also be useful in monitoring other devices within the room. Another non-tomographic method of aligning a patient relies on radiofrequency signals in order to track an implanted transponder. The Calypso® 4D tracking system is a system that provides RF tracking of Beacon® transponders that can be implanted or placed an immobilization device. Some befits of RF tracking include nearly real-time (10 HZ frequency) update in location, accurate and objective coordinate information, and non-ionizing radiation signals.

This lecture will provide an overview of non-tomographic patient alignment techniques that can allow real-time positioning. It will also discuss the strengths and weaknesses of such technology compared to tomographic modalities and specific concerns in radiation therapy.

Educational Objectives:

1. Understand some common concerns in inter and intra-radiation fraction motion.
2. Understand the differences between tomographic and non-tomographic means of patient motion evaluation.
3. Understand the strengths and weaknesses of an RF tracking system in radiation therapy treatments.

WE-D-ValA-04

Synchrony -- Real-Time Respiratory Compensation System for the CyberKnife

C Ozhasoglu*, University of Pittsburgh Cancer Institute, Pittsburgh, PA

Fluoroscopic, ultrasonic and 4D CT studies of the organs in the thorax and abdomen have shown that some organs may move as much as 4 cm due to respiratory motion. If the motion is not compensated for during external beam radiation therapy, the dose coverage to target may be compromised. On the other hand, if the motion is compensated for with an increase of margin, a significant amount of normal tissue may be irradiated unnecessarily. The issue of respiratory compensation becomes more important for hypofractionated treatments and even more so for single-fraction extracranial radiosurgery applications. CyberKnife is an image-guided radiosurgery system that consists of a 6-MV LINAC mounted to a robotic arm coupled through a control loop to a digital diagnostic x-ray imaging system. The robotic arm can point the beam anywhere in space with six degrees of freedom, without being constrained to a conventional isocenter. The CyberKnife has been recently upgraded with a real-time respiratory tracking and compensation system called Synchrony. Using external markers in conjunction with diagnostic x-ray images, Synchrony helps to guide the robotic arm to move the radiation beam in real time such that the beam always remains aligned with the target. With the aid of the

Synchrony, the tumor motion can be tracked in three dimensional space, and the motion induced dosimetric change to target can be minimized without an increase in margin. The working principles, advantages, limitations and our clinical experience with this new technology will be discussed.

WE-D-ValA-05

3D Surface Imaging for PBI Patient Setup

GTY Chen*, DP Gierga, Massachusetts General Hospital, Harvard Medical School, Boston, MA

Image guided radiotherapy has primarily been implemented with technologies that utilize subsurface imaging. Radiography and ultrasonograpy are established methods to localize the target or critical organs on a daily basis. Imaging the patient surface can also have an important role in IGRT. Video-based surface imaging can be an alternative to radiography in patient setup of selected targets, such as partial breast irradiation (PBI). Video also has a role in continuous monitoring of patient position during treatment. There are various approaches to surface imaging; some measure the Cartesian coordinates of multiple discrete optical markers. We have utilized a stereo photogrammetric approach, where a speckle pattern is projected onto the patient surface, and surface topology is measured by cameras mounted from the ceiling. A user defined surface ROI from the treatment du jour is matched with the reference surface topology, and the rigid body translations and rotations required to bring the two surfaces into optimal congruence are determined.

The intrinsic performance of a surface imaging system can be <1mm and $<1^{o}$, which is more than adequate for most clinical situations. Patient studies have been conducted to quantify the setup accuracy of laser, chestwall, and surface imaging, in comparison to ground truth (defined by radiographic clips). In these studies, effects of respiration, breast deformation, and posture variations are analyzed to determine their contribution to the uncertainties in targetry. The target registration error for surface imaging is ~ 1mm relative to clips, and is more accurate than laser or chest wall setup, based on a statistically rigorous analysis.

This lecture will provide an overview of video based surface imaging as a tool for patient alignment in image guided therapy. While the focus is on PBI setup, the evaluation and analysis of how to compare IGRT approaches has general validity.

Educational Objective:
1. Understand basic principles of stereo photogrammetric surface mapping
2. Understand approaches to characterize and validate system performance.
3. Understand clinical factors that affect the Target Registration Error in IGRT.

Professional Panel Room 230A

The HIPAA Dilemma and Medical Physics

WE-D-230A-01

Panel: HIPAA Compliance and the Medical Physicist

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The Health Insurance Portability and Accountability Act of 1996 (HIPAA) made sweeping changes in the ways in which information regarding individuals' health care must be stored and transmitted electronically. Most AAPM members will have some familiarity with the resulting changes to policy and procedures implemented by health care providers and hospitals. The roll-out of Rules developed by the Department of Health and Human Services (HHS) in response to the Act is now approaching completion. With the dust beginning to settle it is a good time to review what is and is not required under the HIPAA umbrella.

The intent of the Act is laudable. It contains provisions to safeguard an individual's access to their own health care information and some degree of control over its use ("Privacy"), provisions mandating standardization of electronic information exchange for health information in order to streamline transmittal of information between health care entities ("Electronic Data Interchange"), and provisions requiring that covered entities take certain measures to safeguard individuals' information against unintended exposure ("Security").

Unfortunately, as is often the case with sweeping Federal regulation, there is a great deal of misinformation and confusion in the marketplace about the Rules and their implications. This arises partly because, while most of the requirements are clear, the detailed mechanisms for compliance must be developed and implemented locally. This is a situation quite analogous to radioactive materials licensing, with which we are all familiar. Often one is unsure of one's degree of compliance until one is actually inspected, a very uncomfortable place to be when there are both fines and bad publicity at stake. Uncertainty creates ample opportunity for unscrupulous consultants to prey on the anxiety of health care administrators by recommending excessive or misdirected "compliance" measures, thus compounding an already difficult transition. We have all seen this dynamic in action.

Another unfortunate outcome of the poorly-informed implementation of layers of unbending bureaucracy in the name of compliance is that sometimes restrictions are imposed locally on information flow which are ultimately against the best interest of the patient. For instance, an absolute local prohibition on releasing patient-specific treatment planning information may be directly in conflict with a Medical Physicist's need to send problematic data to a vendor to obtain timely resolution of a software anomaly.

The bulk of our attention in this session will be directed to clarifying the impact of the Rules on the practicing Medical Physicist. The question is not easily answered as the impact on a given Medical Physicist depends very much on the situation in which the Medical Physicist operates. We have in common that many of us act as *de facto* Information System managers in our departments and as such have a certain degree of practical responsibility for monitoring access to patient-specific information. The degree to which we are formally responsible for compliance may vary greatly, though, depending on the specifics of our contractual relationship to the hospital or other entity for which we are performing services. It is in the Medical Physicist's interest to be clear regarding both the responsibilities and the restrictions on practice that might be included in any agreements regarding HIPAA compliance that they might be asked to sign as a condition of employment. A good working knowledge of the basics of the Act and the Rules is a useful starting point.

We are fortunate indeed to have four expert Panelists representing four different perspectives on these questions. They are respectively (in order of their presentations) a member of the American College of Radiology's legal office, the Chief Privacy Officer for a major vendor of Radiation Oncology information management systems, the Local Security Coordinator for a mid-sized Regional Hospital, and a Senior Analyst with the Department of Health and Human Service's Office of Civil Rights (responsible for enforcement of the Rules).

The goals of this Panel are to:
1. Briefly review the scope, structure and timeline of the Act and subsequently developed Rules, and introduce some of the specific jargon of HIPAA.
2. Clarify to whom the Rules apply and the chain of responsibility for compliance.
3. Discuss the specific impact on Medical Physicists of HIPAA and the local implementation of compliance programs.
4. Dispel some common myths about the requirements imposed by HIPAA and, conversely, highlight compliance issues that may be less widely appreciated.
5. Suggest some proactive strategies that Medical Physicists can employ to prevent conflicts with local compliance policy.

Therapy Scientific Session Room 224 A
IMRT Verification and QA II

WE-D-224A-01
Inter- and Intra-User Variations in Film Based IMRT QA
D Chase*, C Ramsey, B Robison, R Seibert, C Harris, Thompson Cancer Survival Center, Knoxville, TN

Purpose: To measure the inter- and intra-user variations in the manual alignment of calculated and measured doses in film-based IMRT QA. Methods and Materials: Twenty (4 coronal and 16 axial) IMRT film based QA test cases were selected, each detailed by the "QA mode" in the IMPAC information management system. Films were shot in phantoms using a Varian 21EX, and do not contain fiducial marks. The treatment plans were created using the Pinnacle treatment planning system. Four of the films had known MLC problems, and were designed to fail the QA analysis. The films and corresponding calculated doses were placed on the internet for download. Participants were instructed to download the files, perform manual registration using the RIT113 software, save the registration films and return the test package to the investigators. Participants were instructed not to change the regions of interest and to indicate if each case would pass or fail their particular institutional criteria. Returned data was then analyzed for inter- and intra-user variations in the manual alignment. **Results:** As of abstract submission, six respondents had been analyzed. The respondents had a wide range of passes and failures. Five out of the six respondents correctly identified the four films with known problems. One respondent incorrectly identified Patient #4 as a pass, but did note that the film was overly cropped. On average, the respondents indicated that seven of the films would not pass. Without fiducial marks on the film, each user placed the registration point in unique locations. As a result, each user had a unique QA analysis. Errors in the selection of registration points were directly related to false negatives. **Conclusions:** In order to minimize inter- and intra-user variation, fiducial marks should be used to register the calculated and measured films in IMRT QA.

WE-D-224A-02
Evaluation of Kv CBCT-Based Dose Verification
C Wang*[1], Y Yang[2], L Xing[1], (1) Stanford University School of Medicine, Stanford, CA, (2) University of Pittsburgh Cancer Institute, Pittsburgh, PA

Purpose: To evaluate the accuracy of using kilovolt cone-beam CT (CBCT) for dose calculation and investigate the feasibility of using kv CBCT for patient dose verification. **Method and Materials:** A solid water phantom and phantoms consisting of a stack of polystyrene slabs with three types of 3cm inserts (the same polystyrene material, lung- and bone-equivalent material) were used to evaluate the accuracy of CBCT-based dose calculation. Planning CT (GE Discovery-ST) and CBCT (Varian Trilogy) images of each of the phantoms were acquired. In each case, single-beam plan with a variety of field sizes and 5-beam IMRT treatment plans were prepared based on both planning CT and CBCT images. In addition, the optimized fluence maps from the CT-based IMRT plan were used recomputed the dose on the CBCT phantom images and the results were compared with that of the original treatment plan based on CT. Point dose and film measurements were also carried out and compared. The same comparison also was performed for a prostate patient and a head-and-neck patient. **Results:** The recalculated dose distribution based on the CBCT and the intended fluence maps from the treatment plan agreed each to less than 3% for the homogeneous solid water or polystyrene phantoms. A similar level of agreement was found between the calculations and point dose measurements. For inhomogeneous phantoms, the discrepancy between the two sets of calculations depended on the spatial location, which ranges from 1% to 6%. The comparison of DVH curves suggested the same. When compared with measurements, a larger discrepancy was observed between the CBCT-based calculations and measured doses. **Conclusion:** Our data suggest that, at present, the image quality of the CBCT is not satisfactory for accurate dose verification, and the Hounsfield number should be corrected before CBCT images can be utilized for dose verification.

WE-D-224A-03
A 4D IMRT QA Device
B Nelms*[1], W Tome[2], (1) Canis Lupus LLC, St. Louis, MO, (2) University of Wisconsin, Madison, WI

Purpose: Many radiation therapy targets move during treatment. Some emerging technologies allow clinicians to accurately define and prescribe to "Tumor Motion Envelopes" (TME). In the case of IMRT delivery, clinicians must consider the temporal nature of the modulation in association with the target motion within the TME. There is a need for a 4D IMRT QA device that can incorporate and analyze customized intrafractional motion. **Method and Materials:** (X, Y, Z)(T) coordinates representing a motion kernel were entered into a software application. The software transformed the kernel into a beam-specific projection, previewed the motion in real time, and drove a precision X-Y motorized device. An existing planar IMRT QA measurement device (MapCHECK) was mounted on the device. The subset of measurement positions that intersected the target in the beam's-eye-view of a single phase of the breathing cycle were defined as "tumor-rays" and analyzed for dose uniformity between multiple fractions. **Results:** In the first efficacy study, two lung patient target motion kernels were derived from 4D CT studies. From each kernels, a TME was formed by convolving the motion kernel with the single-phase target volume. Dose was prescribed to the TME and delivered with open fields and three IMRT modalities – solid modulators, SMLC, and DMLC – for comparison. The 4D IMRT QA device effectively collected tumor-ray data and allowed the analysis of degradation in dose uniformity due to a moving target within a static TME. Gating techniques were considered as well. **Conclusion:** The combined software and hardware solution for customized 4D IMRT QA proved to be an effective tool for assessing IMRT delivery under conditions of intrafractional motion. It was also an interesting tool for the assessment of delivery gating. **Conflict of Interest:** Research partially sponsored by Sun Nuclear Corporation

WE-D-224A-04
Verification of the Lung Dose Calculation of a Commercial IMRT Planning System Using a Realistic Lung Phantom
k Aljarrah*[1], C Pope[2], SB Jiang[2], Jordan University of Science and Technology, Irbid, Jordan, Massachusetts General Hospital, Boston, MA

Purpose: The purpose of this work is to find out the accuracy of a popular IMRT TPS system (NOMOS CORVUS) in lung dose calculation. **Method and Materials:** Up top now most of lung dose measurements have been done only for slab geometry of inhomogeneity and for a single beam. In this work, we use a realistic lung phantom and deliver all fields of realistic IMRT plans. The phantom is supplied with cylindrical inserts, made of equivalent materials of lung, bone, and tissue, which were used to load the dosimeters. The dose to phantom was calculated, for 16 IMRT plans, with the Corvus system. Verification was done with measurements using TLDs and ionization chambers measurement, as well as Monte Carlo simulation. For each treatment plan, the dose was verified at points located in lung, bone, and tissue. **Results:** The comparison of the collected data shows that the dose to the lung calculated with Corvus was overestimated by 2% to 10% relative to the Monte Carlo results, and by 2% to 7% relative to the ion chamber measurements. The TLD measurements show better agreement to the Monte Carlo results than to the Corvus results. In bone and tissue the dose results show an agreement, within ±3%, among all the calculations and measurements. **Conclusion:** The dose calculation accuracy in lung has been estimated for an IMRT planning system. It indicates that the dose algorithms have to be improved in order to have an accuracy of a few percent in lung.

WE-D-224A-05
Developing a Comprehensive Patient-Specific QA Procedure for IMRT
W Luo*, J Li, R Price, L Chen, J Fan, Z Chen, T Lin, L Wang, C Ma, Fox Chase Cancer Center, Philadelphia, PA

Purpose: To develop a comprehensive patient-specific IMRT quality assurance (QA) procedure that verifies both dose calculation and dose delivery. **Method and Materials:** IMRT plan delivery is well described by actual gantry angles, collimator angles, jaw settings, MUs, and couch angles, which are output from Record and Verify system (R/V), as well as actual MLC leaf positions and fractional MUs recorded in MLC log files.

MLC log files are used to rebuild leaf sequence files for actual leaf motion. The rebuilt leaf sequence files and the R/V output are used in the Monte Carlo simulation with patient CT to verify both dose calculation and dose delivery before treatment. Ion chamber or film measurement can be used to further investigate other causes when large errors are encountered. Post-treatment QA can be performed with EPID that records the intensity maps behind the patient which include the dosimetric and patient setup information during treatment. The intensity maps above and behind the patient are re-constructed using phase space data and compared with the measured EPID images to verify the dose delivered in the patient. **Results:** This method was tested with ion chamber measurement for four real prostate plans and the agreement was within 2%. A linear correlation between average leaf position error and target dose error was found. Average leaf position error of 0.2mm resulted in about 1% error in target dose. Eight IMRT prostate plans were used in this study and the errors caused by dose calculation and delivery did not cause significant errors in the dose delivered (<2.0%). **Conclusions:** We are developing a comprehensive patient-specific IMRT QA procedure utilizing the Monte Carlo simulation, MLC log files, R/V output and EPID. This method can be used to verify both dose calculation and dose delivery for pre- and post-treatment IMRT QA.

WE-D-224A-06

Comparison of Film Based IMRT Verification with EPID Based Fluence Verification

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Purpose: With increasing application of IMRT, its QA should become much more time-efficient. This work compares patient specific QA procedures based on absolute EPID dosimetry with EDR2 absolute film dosimetry. A gamma value acceptance protocol is assessed for both methods. **Method and Materials:** Our patient specific QA method is a fluence check of the dynamic IMRT fields. With film dosimetry, each field is delivered on film perpendicular to the beam at 3cm depth in polystyrene. Gamma values are calculated to compare measurement and TPS calculation. For EPID, a commercial portal dosimetry system was used. The fluence distribution calculated with a portal dose prediction algorithm was compared with the measurement.
As the gradients in the EPID signal are much steeper than phantom dose distributions, the gamma value calculation algorithm was adapted for taking into account the interplay between quantization and high gradients.
For the 70 fields of the reference set (14 patients) gamma values were calculated for 81 constraint pair combinations (1mm to 5mm,1% to 5%). An agreement score (AS) was calculated as the percentage of pixels in the field aperture having gamma values smaller than 1. Agreement was considered perfect for AS>99%. Sensitivity of the procedure was set by applying an acceptance level of 90% perfect agreement on the reference set. **Results:** The 90% acceptance is reached at 3.6%\3.6mm for denoised film dosimetry and at 3.1%\3.1mm for EPID dosimetry. Noise in the measured film dose distribution pulls the iso-sensitivity lines to lower values of the % constraint. The 90% acceptance is reached at 2.76%\2.76mm.**Conclusion:** There is confirmation for the important influence of noise on gamma value based acceptance protocols for film dosimetry. The results show that in order to have equal sensitivity for EPID and film QA, different gamma value constraint pairs should be used.

WE-D-224A-07

Enhanced Efficacy in Helical Tomotherapy Quality Assurance

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Purpose: The Helical Tomotherapy Image Guided Radiation Therapy (IGRT) system delivers highly conformal dose distributions in a dynamic fashion. This system is also capable of acquiring MV-CT images and registering them with the planning CT for accurate target localization. Efficient QA tools are necessary for the effective implementation of this technology. This work describes the design of a custom phantom for daily QA of a Helical Tomotherapy linear accelerator. **Materials and Methods:** A custom designed 20x20x20cm^3 water-equivalent phantom was fabricated for this purpose. Eight ionization chambers are positioned inside the phantom. Low and high electron density plugs along with a specific image-resolution-plug are incorporated into the phantom for testing the image quality indicators. This phantom also includes two slide-out film cassettes for planar dose verification. The commercial eight-channel electrometer is used. Daily QA is performed in the following three steps;
1) *Static Beam Quality Tests*: Machine output, percent depth dose and off-axis factors are checked simultaneously for a 5x40cm^2 open field.
2) *Image Quality and Registration*: The QA phantom is off-set to a known position and an MV-CT is obtained. After verifying the image quality, MV-CT images are registered with planning CT to determine the suggested shift accuracy.
3) A*ccuracy of the helical delivery:* Treatment plans with two targets (separated by 12cm inferior-superiorly) are used to test the helical delivery. Film dosimetry will detect errors such as couch position inaccuracies that could be missed by the point-dose measurements.
Results and Discussion: This QA procedure is designed to verify vital components of the Tomotherapy system such as beam quality, image quality, accuracy of the target localization, and helical delivery. Typical time required for this QA testing is only 30 minutes. **Conclusions:** This QA process is simple, efficient and verifies several important dosimetric and geometric parameters.

Supported in part by Tomotherapy, Inc.

WE-D-224A-08

Monte Carlo Dose Verification of Prostate Patients Treated with Simultaneous Integrated Boost IMRT

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Purpose: To evaluate the dosimetric accuracy of Superposition/Convolution (SC) and Monte Carlo (MC) calculated dose distributions for simultaneous integrated boost (SIB) prostate cancer intensity modulated radiotherapy (IMRT) compared to experimental (film) measurements and the implications for clinical treatments. **Method and Materials:** Twenty prostate patients treated with in-house SIB-IMRT protocol were selected. SC-based plans used for treatment were re-evaluated with EGS4-based MC calculations for treatment verification. Accuracy was evaluated with-respect-to film-based dosimetry. Comparisons used γ-index, DTA, and superimposed dose distributions. The treatment plans were also compared based on dose-volume indices for targets and critical structures. **Results:** Flat-phantom comparisons demonstrated that the MC algorithm predicted measurements better than the SC algorithm (%γ>1 8.4% for MC vs. 18.3% for SC). The average $PTV_{prostate}$ D_{98} and PTV_{nodes} D_{95} indices agreement between SC and MC was 1.2%±1.1 (range: -38%, +0.1%) and 1.6%±1.5 (range: 3.6%, 0.6%) respectively. For rectum, the average differences in SC and MC calculated D_{50} ranged from -3.6% to 3.4%. There were up to 34.3%±42.5 (range: 0.2%, 115%) differences between SC and MC calculated average D_{50} index for small bowel. This large deviation is due to large differences in small bowel volume within the treatment field and small bowel dose for each patient. For femurs, the differences in average D_{50} reached up to 9.6%±4.5 (range: 1.2%, 14.5%). **Conclusion:** MC agrees better with film measurements than SC. Although on average SC-calculated doses agreed with MC calculations within the targets within 2%, there were deviations >10% for some patient's treatment plans. The major source of these deviations may be due to the inaccuracies in fluence prediction model for SC calculation. The use of SC may compromise the clinical outcome of patients and MC-based IMRT would be beneficial for IMRT plan optimization. (Supported by NIH-R0198524).

WE-D-224A-09

Proposed Pass/fail Criteria for IMRT Patient Specific QA

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Purpose: To establish an acceptable quality assurance (QA) criteria for IMRT patient specific QA. There are no established criteria regarding agreement between patient's planned dose distributions versus QA measurements. **Method and Materials:** A series of MLC QA test patterns were run to detect/correct MLC leaf positional inaccuracies for a Varian 2100C and Elekta Synergy (both with 80 leaf MLC). MapCheck, a 2D diode array system, was used to determine optimal correctional parameter, Dosimetric Leaf Gap (DLG), used in the Varian Eclipse/Helios treatment

planning system (TPS) (accounts for effect of MLC rounded-leaf end geometry). Patient's IMRT plan was checked by resetting all fields to a fixed gantry angle (beam down), delivering summed dose of each beam, measuring with MapCheck, then comparing with TPS calculated dose distribution. QA results for a total of 48 segmented MLC (SMLC) IMRT cases (37 prostate, 9 head and neck, 1 pelvis, and 1 brain) were reviewed. **Results:** MLC position uncertainties were reduced from 0.3-0.4 mm to 0.1-0.2 mm by a careful calibration. An optimal DLG of 2 mm was determined for Elekta Synergy. Using criteria of ±3% dose agreement or ±3mm distance to agreement (DTA), measured absolute dose distributions agreed with planned dose distributions as follows: prostate: mean 98%, 2.3% S.D.; H&N: mean 89.1%, 8.4% S.D.; pelvis: mean 90.5%; brain: mean 91.1%; for the total 48 cases, mean 96%, S.D. 5.4%. **Conclusion:** MLC positional accuracy and having optimal correctional parameter within the TPS are two key factors to ensure IMRT delivered dose in good agreement with calculated dose distribution. Using MapCheck as described, we have implemented the following pass/fail criteria for patient specific QA measurement results: 85% of points within ±3% and ±3 mm DTA in absolute dose. Our clinical experience shows that this is achievable even with the most complicated H&N cases.

Therapy Scientific Session Room 224 C
Clinical Measurements II

WE-D-224C-01
Water Equivalent Multichannel Dosimeter Arrays for External Beam Radiotherapy

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Introduction: Scintillation dosimeters consisting of a single scintillating fiber coupled to an optical fiber and read with a CCD camera have shown accurate dose measurement in high-energy external beam radiotherapy. This work presents the next step, which is to investigate the development of a multi-channel dosimeter array in conjunction with a CCD camera for photodetection. Methods and Materials: The light collection of the CCD camera (Apogee Alta U2000c) was first studied to evaluate the maximum number of detectors that can be read simultaneously. We then looked at possible sources of dose perturbation with a single-fiber detector surrounded by other optical fibers. We constructed a prototype array with 10 detectors. Finally, depth-dose and cross-plane profiles were compared with measurements taken with small ion chambers (Exradin models A14 and A16). **Results:** We found up to 3000 individual fibers could be detected simultaneously with the full CCD chip. No dose perturbations were seen when a plastic optical fiber was used to transmit the light from the scintillating fiber to the CCD. Depth dose curves measured in water with a single scintillation dosimeter with up to 75 plastic optical fiber in the beam showed no discrepancy to within 0.3% when compared to the same curve taken with an ion chamber and without the plastic fibers. The ten-fiber prototype allowed precise evaluation of profile and depth dose curves in a single irradiation. **Conclusion:** This work has shown that use of a multi-channel scintillation dosimeter is feasible. The prototype of 10 detectors produced excellent results and could be extended up to 3000 detectors in the near future.

WE-D-224C-02
High Dose Rate Mode Linear Accelerator Based Stereotactic Radiosurgery and Image Guided Radiation Therapy

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Introduction: In order to improve the standard linear accelerator's ability to address the demands of intracranial and extracranial stereotactic radiosurgery as well as for image-guided and intensity modulated radiotherapy, a high dose rate output accelerator was developed. The objective of this study was to assess the device performance and compare it to standard accelerators. **Materials and Methods:** The 6 MV x-ray beam of a Siemens Oncor linac was modified by removing the flattening filter, enabling dose rates to reach 1000 MU per minute. Ion chambers, diodes, and film dosimeters were used to assess monitor chamber behavior, energy, and dose profile characteristics. Treatment time required for radiosurgery treatments in 40 patients was measured. **Results:** Even at this high dose rate, the linac dosimetry system remains robust; constancy, linearity, and beam energy remain within 1% for 3 to 1000 MU. Measurements at incrementally reduced dose rates (1000 to 300 in 100 MU increments) showed the output calibration to fall from 1.000 cGy/MU to 0.994 cGy/MU, with an average value of 0.997 cGy/MU. Over this range of dose rates the beam energy held consistent, with the ratio of percent depth dose values within 0.5%. Dose profiles for larger field sizes are not flat, but they are radially symmetric and as such able to be modeled by a treatment planning system. Radiosurgery treatment times, computed here as the beginning of x-ray delivery until the end of treatment, were reduced to an average of 2 minutes and 18 seconds per arc, or 11 minutes 27 seconds per isocenter. **Conclusions:** Even at this high dose rate, the linac dosimetry system remains robust. Because stereotactic IGRT can require significantly longer times for treatment delivery, the advantages of the high dose rate design should be pursued.

WE-D-224C-03
Surface Dose Measurements for Intensity Modulated Radiation Therapy

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Purpose: To measure the surface and near-surface doses for a variety of IMRT delivery and planning techniques, and to determine the optimal PTV size and planning scenerio for skin dose maximization or minimization. Methods and Materials: A primary PTV was defined on an anthropomorphic head phantom for a typical parotid-sparing head &neck treatment. Treatment plans were created with 0, 1, 2, 3, 4, and 5-mm separation between the skin surface and PTV boundary. IMRT treatments were planned using the Pinnacle treatment planning system and delivered on a Varian 21EX with a 120-leaf multileaf collimator. Inverse planning was performed using Direct Machine Parameter Optimization (DMPO) for step and shoot IMRT and gradient decent optimization for sliding window leaf sequencing IMRT. Helical tomotherapy cases were planned using the TomoTherapy HI-ART treatment planning system and delivered using a Tomotherpy HI-ART treatment delivery system. Surface doses were measured for each of the treatment deliveries using film placed in an anthropomorphic head phantom and thermoluminescent dosimeters (TLD) chips placed on the phantom's surface. A chip-specific TLD surface calibration factor was determined and applied to the raw TLD readings to account for measurement efficiency at the surface. Relative dose measurements were made using calibrated film placed in the phantom. Surface and near-surface doses were measured from digitized film images for a 1.5-cm range inside the phantom to in-air outside the phantom. **Results:** Surface dose values measured with film were consistently lower, while TLD measurements were higher than planned for the cases studied. **Conclusions:** The helical tomotherapy treatment plans were found to have better parotid sparing and PTV dose uniformity than both the step-and-shoot DMPO and sliding window plans. The tomotherapy planning system was observed to overestimate the surface dose from 9 to 18 percent.

WE-D-224C-04
Investigation of MLC Effects On Secondary Neutron Spectra for Varian, Siemens, and Elekta

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Purpose: To compare the secondary neutron spectra in accelerators with different multileaf collimator (MLC) configurations. The addition of MLC, have lead to design modifications in modern linear accelerators; Elekta has replaced upper collimating jaws with MLC, Siemens has replaced lower jaws with MLC, Varian added tertiary level MLC. **Method and Materials:** Measurements were made of the neutron fluence and energy spectra for several modern accelerators. The detector consisted of ^{197}Au activation foils, which were placed on the surface of the holder and inserted into Bonner Spheres. An HPGe detector was used to measure counts under the 411keV photopeak for each foil. Data were unfolded with the MXD_FC33 code with a response matrix specifically calculated for this measurement system using MCNP5. In this investigation, neutron spectra, fluence per MU, and ambient dose equivalent are reported for 18MV x-ray beams generated by Varian 21EX, Siemens Oncor, and Elekta Precise

accelerators. The impact of the jaw and MLC configuration were further studied for the Varian 21EX by taking measurements following the complete removal of the MLC. **Results:** Jaws and MLC closed: similar spectra for the Siemens and Elekta but the Varian spectrum has a lower energy distribution. Varian X and Y jaws closed: With MLC in place, less neutrons are detected and spectrum shifts to lower energies (compared to MLC removed). MLC attenuates neutrons created higher in treatment head. Varian X and Y jaws retracted: With MLC in place more neutrons are detected and the spectra shifts to lower energies (compared to MLC removed). The MLC attenuate neutrons created higher in treatment head but MLC become the primary source of contamination neutrons when jaws retracted. **Conclusion:** Secondary neutron spectra are different in accelerators with different MLC configurations. This difference translates to a difference in ambient dose equivalent to patients receiving high-energy radiation therapy.

WE-D-224C-05

Investigation of Superficial Dose From a Static TomoTherapy Beam

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Purpose: To determine the magnitude of superficial doses produced from a static TomoTherapy beam directed at varying SSDs and angles of incidence. **Method and Materials:** Measurements of superficial doses have been made along the central axis of a static TomoTherapy beam at normal incidence for SSDs of 55, 70, and 85 cm for typical TomoTherapy jaw sizes (40x2.5 cm^2 and 40x5 cm^2). Measurements have also been made along the central axis of a TomoTherapy beam at oblique angles of 30˚, 45˚, 60˚, 75˚, and 85˚. Data were collected with a Gammex Model 449 parallel-plate chamber embedded in a solid water phantom and LiF TLD powder. For comparison, measurements have been made on a 6X Varian 2100C accelerator with the same jaw width (5 cm at 85 SSD) and at the same SSDs. Percentage depth dose (PDD) profiles for depths $\leq$ 2 cm have been obtained from the data. **Results:** TomoTherapy surface dose measurements vary weakly with SSD, ranging from 16%-18% for the 40x5 cm^2 field, and from 12%-14% for the 40x2.5 cm^2 field. The measured doses increase rapidly with depth, with PDD>90% obtained at depths < 0.6 cm. Surface dose ranges from 17%-26% on the Varian 2100C for the same SSDs and 5cm jaw width. TomoTherapy surface dose increases from 16% to 43% as the angle of incidence increases from 0˚ to 85˚ for the 40x5 cm^2 field and increases from 12% to 40% for the 40x2.5 cm^2 field. **Conclusion:** TomoTherapy surface doses do not vary significantly with SSD but increase dramatically with increasing angle of incidence. Generally, the magnitude is less than that measured from a conventional, flattening filter-based linac. These data should assist in assessing the accuracy of the TomoTherapy planning system in the calculation of superficial doses.

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WE-D-224C-06

Leakage Characteristics of Two Common Multi-Leaf Collimators: Implications for Intensity Modulated Radiotherapy

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Purpose: To evaluate leakage characteristics of two Varian MLCs during IMRT delivery. **Introduction:** IMRT increases total body dose due to increased leakage proportional to the additional monitor units required. During MLC IMRT delivery, collimator jaws are positioned outside the edges of the entire intensity map, increasing the prevalence of leakage through and potentially around the MLC. The magnitude of the latter component is dependent upon the physical size of the MLC. **Method and Materials:** The Varian Mark-I 52-leaf and Millennium 120-leaf MLCs have widths of 26 and 40cm, respectively, in the direction perpendicular to leaf motion. Identical, 1cm bixel-size small (8x9cm^2), medium (12x16cm^2), and large (20x24cm^2) intensity maps were delivered in SMLC mode with each MLC using 6MV photons. Ionization chamber measurements were performed outside these fields at the surface and 10cm depth in a patient-simulating phantom at 15, 20, 30, 40, and 50cm off-axis both along and perpendicular to the direction of leaf motion. **Results:** Mark-I leakage in the leaf motion direction was very similar to Millenium-120 leakage in either direction. However, Mark-I leakage was considerably higher perpendicular to the leaf motion direction. This increase was apparent at all points, with a maximum of 100-150% at 20-30cm off axis for all fields. The average increase for all fields and positions was 90% at the surface and 65% at 10cm depth. Previous investigations have indicated significant risks of secondary malignancy induction associated with total body doses encountered in IMRT. Our results indicate that this risk is nearly doubled using a Mark-I MLC when the patient axis lies along the narrow dimension of the MLC.**Conclusion:** The Mark-I MLC can profoundly increase total body dose in comparison to a wider MLC. This increase may be largely alleviated by judicious choice of collimator angle. This risk should be considered during IMRT planning.

WE-D-224C-07

A Comprehensive Patient-Specific IMRT Quality Assurance Procedure On Hi-Art Tomotherapy® Unit

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Purpose: To present a comprehensive patient-specific IMRT QA procedure on Tomotherapy® unit using ion chamber and radiographic film for those facilities with RIT® film dosimetry system. **Method and Materials:** A cylindrical Virtual Water® phantom was scanned in CT with an ion chamber in the hole 1.5 cm below the middle coronal plane. Three-dimensional dose calculation in fine grid using treatment beam was performed to the phantom which is appropriately positioned so that the measuring point and plane are within the volume of interest. A sheet of Kokak® EDR-2 Readypack was sandwiched between two halves of the phantom and pricked on green lasers. Film exposure and ion chamber measurement were made simultaneously. To verify planar absolute dose distribution, the film was calibrated in a separate sheet of the same batch on the same day IMRT QA was performed. To facilitate the film calibration and film dosimetry analysis on Tomotherapy planning station, an in-house software was developed to perform step-valley film calibration and film image data conversion from RIT® format to DICOM format which is acceptable by the current version of Tomotherapy planning system. **Results:** 213 patient-specific IMRT QA procedures have been performed on Tomotherapy unit since it was installed about two years ago. The average discrepancy between ion chamber measurement and dose calculation in phantom is 1.74%. Film dosimetry results agree with ion chamber measurements in an average discrepancy 1%. Three cases have failed the QA procedure based on 5% discrepancy criteria. **Conclusion:** Three-dimensional dose calculation algorithm for helical IMRT works very well in homogeneous phantom. This QA procedure is clinically practical and necessary when independent dose calculation tools are not available. It is feasible to verify two-dimensional absolute dose distribution using radiographic film if it is calibrated against ion chamber reading which is traceable to ADCL or NIST.

WE-D-224C-08

Peripheral Dose to the Patient Due to Kilovoltage Cone Beam Computed Tomography

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Purpose: To quantify the peripheral dose outside the imaging field of view (FOV) received by patients undergoing kV CBCT procedures.
Methods and Material: A 0.6 cc Farmer-type chamber and specially designed cylindrical water phantom were utilized to make the dose measurements. The main section of the phantom, constructed of Plexiglas©, is 30 cm in diameter and 50 cm in length, simulating an average patient body. The phantom is placed on the treatment couch with its axis coinciding with the axis of rotation of the gantry. An ion chamber holder rests in a slot on the top of the phantom, and allows the ion chamber to be placed at any depth, and at any point along the length of the phantom. A solid water cylindrical phantom 20 cm in diameter and 16 cm long was placed at the superior end of the water phantom to simulate a patient's head. Measurements were made on an Elekta Synergy treatment unit for various kVp, FOV, depths and distances from the central axis. A limited set of measurements were also made with a RANDO phantom to simulate the effects of typical in homogeneities. For comparison, dose measurements

were made in similar geometry using 6MV and 18MV beams at doses equivalent to a typical treatment fraction. **Results:** For an acquisition technique of 120 kV, 80 mA, 1.6 mAs/frame and 620 projections, using the M10 collimator, the dose 20 cm from the CAX was measured to be 0.15 cGy at depth 15 cm depth and 0.11 cGy at depth 2 cm. The dose outside the FOV was typically a factor of 6 smaller than the MV dose. **Conclusions:** Although small when compared to the dose from the MV beam, the peripheral dose due to kV imaging may be significant if the CBCT procedure is applied daily.

WE-D-224C-09

Dosimetric Evaluation of Proton Field Matching by a Robotic Patient Positioner

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Purpose: The objective of this study is to evaluate the accuracy from a dosimetry point of view with which proton field matching can be accomplished. **Method and Materials:** This proton therapy center currently treats patients with a nominal 208 MeV proton beam in a single Fixed Horizontal Beam Line (FHBL) room that employs a double passive beam spreading system with a fixed range modulator. The FHBL room takes advantage of a novel robotic patient positioner system (PPS) providing 6 degrees of freedom with a specified accuracy of 300 microns when transiting up to a 200 kg payload.

To investigate field matching doses three methods are used: calculations from a treatment planning system, film dosimetry measurements and scans using a miniature ionization chamber. The field delivery for this study consists of four proton fields matched by the robotic PPS. The measurements are performed in a solid water phantom for the film and a water phantom for the ionization chamber scans **Results:** The planned dose delivery for the central field is normalized to 100%. The average relative dose values in the field junctions are 128%, 135% and 130% for the ionization chamber scans, film dosimetry and treatment planning calculation, respectively. In this case this was thought to be clinically acceptable as the volume lay entirely within the target. **Conclusion:** Proton therapy is suitable for treating volumes of relatively large area and shallow depth. In this way the ranged property of the protons can spare underlying structures. The sharp proton penumbra and precision of a robotic patient positioner simplifies field matching. Further study is underway with a half beam block to investigate the range of junction doses that can be expected under a variety of field matching conditions.

Workshop — Room 230 C

Ultrasound QC Workshop - II

WE-D-230C-01

Ultrasound QC Workshop

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Quality control testing of ultrasound scanners is gaining importance as the use of diagnostic ultrasound become more quantitative in nature and the systems and probes more complex in design. As evidenced by the rise in popularity of the American College of Radiology's ultrasound accreditation program, the need for comprehensive quality control programs is clear. This workshop is designed to provide attendees an opportunity to learn the impact of scanners and probes on various aspects of image quality and to refresh their skills in ultrasound QA/QC testing. The essential physics of ultrasound imaging and instrumentation will be reviewed. QA/QC testing procedures required by accreditation programs and advisory organizations will be presented. The impact of scanner and probe deficiencies on both B-mode and Doppler performance will be demonstrated. Tools for analyzing probes will also be demonstrated.

Finally, a discussion of quality control of prostate brachytherapy ultrasound will be presented. In the second half of the workshop, attendees will be given the opportunity to use the various tools and phantoms in a hands-on environment. Experienced instructors will be at the ultrasound scanners to guide the exercises.

Two identical sessions will be conducted, one in the morning and the second in the afternoon.

Educational Objectives:
1. To learn the effect of parameter settings and probes on various aspects of ultrasound imaging.
2. To observe the impact of system and probe deficiencies on ultrasound performance and image quality.
3. To become acquainted with various ultrasound QC phantoms and test tools and learn their proper use.

Imaging Scientific Session — Room 330 D

Advances in Radiographic Imaging

WE-E-330D-01

The Production of Ultrafast Bright K-Alpha X-Rays From Laser Produced Plasmas for Medical Imaging.

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Purpose: To show the potential of improving image quality with a cleaner, brighter, quasi-monochromatic X-ray micro-source via laser produced plasmas (LPP). **Method and Materials:** First generation targets consisting of ten micron thick gold formed into free-standing pyramids have been built. PIC (Particle-In-Cell) simulations have been performed in order to validate this target geometry. Preliminary experiments with a Ti-Sapphire CPA laser have been achieved with these targets. Second generation parabolic cone targets with an optimal angle for electron transport have also been built. This new nano-fabricated target could optimize X-ray source characteristics. **Results:** PIC (Particle-In-Cell) simulations show that conical targets optically guide laser light resulting in a higher density of hot electrons at the apex These simulations show a possible ten times augmentation in hot electron density and a three times increase in electron temperature with a conical verses flat target. This increase in collimated suprathermal electrons boosts total photon yield as well as possibly enhancing line emission verses the bremsstrahlung continuum. Preliminary experiments demonstrate a three-fold higher X-ray yield and a two-fold reduction in focal spot with the pyramidal verses the flat target. Furthermore, the geometry of the conical targets not only reduces focal spot size to a few microns and pulse duration to a couple picoseconds, but allows the particles to escape the target perpendicular to the surface resulting in a particle-free, ultra-short X-ray micro-beam. **Conclusion:** Comparing LPP X-ray source parameters to that of a standard X-ray tube shows substantial improvements in focal spot size, photon flux, spectral range and emission duration. Focusing on target design can provide a cleaner, brighter, quasi-monochromatic X-ray source that could improve image quality in any medical diagnostic regime. Such advancements show promising applications in mammography and angiography. **Conflict of Interest:** Research sponsored by DOE/NNSA under University of Nevada Reno grant #DE-FC52-01NV14050.

WE-E-330D-02

Characterization of Breast Calcifications Using X-Ray Diffraction

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Purpose: Coherent scatter imaging has been developed to elucidate the chemical composition of calcifications. Breast calcifications can be divided into two broad categories. Type I are calcium oxalate dehydrate, while Type II are calcium hydroxyapatite. Type II calcifications are known to be associated with carcinoma. It is generally accepted that the exclusive finding of type I calcifications is indicative of benign lesions. **Method and Materials:** An imaging system has been built that utilizes a molybdenum target x-ray tube with niobium filtration to isolate the molybdenum K_α characteristic radiation. The system is designed to interrogate calcifications in the field with a pencil-beam of radiation. The transmitted beam is attenuated, and the scattered beam is recorded on an x-ray image intensifier

optically-coupled to a CCD camera. The system is typically operated at 36 kVp and 25-100 mAs. **Results:** Reagent grade calcium oxalate and calcium hydroxyapatite were made into blocks of thickness 42-510 mg/cm^2. Pinhole sizes varying from 0.3-2.0 mm in diameter were tested to observe the effects of irradiation area on the resolution of the diffraction patterns. All pinhole sizes produced distinctive spectra, but a pinhole size of 0.75 mm appears to be near optimal, as there is sufficient angular resolution and photon fluence to produce distinguishable diffraction patterns. Scattering materials (simulating glandular tissue and fat) were placed upstream and downstream of the calcific material to probe the influence of the surrounding tissue on diffraction. Material thicknesses >1 cm dramatically degraded the measured diffraction patterns. Analysis of diffraction patterns show that calcifications are readily discernable based upon their scattering characteristics. We are able to match these diffraction patterns to calculated theoretical patterns when the later is convolved with a Gaussian-based filter. **Conclusion:** We have demonstrated in proof-of-principle that we can discern different types of calcifications using coherent scatter imaging.

WE-E-330D-03

Feasibility of High-Resolution Contrast Enhanced Digital Mammography

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Purpose: This study is aimed at investigating the feasibility of high-resolution contrast enhanced digital mammography (CEDM). **Method and Materials:** Recent studies report certain promising aspects of contrast mammography [Jong et al., Radiology 228, 842-50, 2003] for identifying subtle lesions that might not be detectable by conventional mammography. In this study we investigate certain physical aspects of high-resolution CEDM. The objective was to study the feasibility of high resolution and low dose CEDM with acceptable contrast characteristics. We used a prototype imager [Vedantham et al., Med Phys 31, 1462-72, 2004] that consists of a 2 x 2, CCD array. The imager was operated in a 78 μm mode by pixel binning. Computational studies with a 49 kVp, W spectrum with 0.6 mm Cu added filtration (1st HVL: 1.9 mm of Al) indicated dose levels in the range of 0.1-0.5 mGy for a 5 cm thick, 50% glandular breast for the entire mammography exam. Theoretical modeling was performed using the parallel cascaded approach described by Cunningham and Yao [Proc. SPIE 3336, 220-30, 1998, Med Phys 28, 2020-38, 2001] for various physical conditions. In addition, experimental evaluation of the physical characteristics of the imager was conducted. **Results:** The resolution characteristics at 10% MTF was ~7.8 and ~4.2 cycles/mm and the DQE(0) estimate was ~0..4 and ~0.65 for 150 and 450 μm thick CsI:Tl scintillators respectively. Model results for pixel size range of 39-156 μm and CsI:Tl thickness range of 150-300 μm indicate that a 250-300 μm thick CsI scintillator with an imager pixel size of 78 μm could potentially offer a reasonable trade-off between spatial resolution and DQE(f) characteristics. **Conclusion:** The results suggest that high-resolution CEDM appears to be feasible at dose levels substantially lower then digital mammography. This research was supported in part by: NIH-NIBIB Grant RO1-EB002123 and the Georgia Cancer Coalition.

WE-E-330D-04

High-Performance Dual-Energy Imaging with a Flat-Panel Detector: Answering the Challenge of Dual-KVp Flood-Field Correction

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Purpose: Flood-Field correction is a critical step in achieving high image quality in digital radiography (DR) and dual-energy (DE) imaging. The optimal Dark-Flood correction scheme suggests collection of Flood-Fields at the same technique as the Projection data. In practical applications calibration data are often collected at the start of the day, and Flood-Fields not collected for all techniques. The problem of proper Flood-Field correction is compounded in DE imaging where two projections at different energies need to be considered. The purpose of this study is to quantitatively examine the effects of various Flood-Field correction schemes on DE imaging performance. **Method and Materials:** In DE imaging two Projections are collected: a low-energy image (e.g., 60-90 kVp) and a high-energy image (e.g., 120-150 kVp). Five Flood-Field correction schemes were considered: optimal correction (Flood-Field at the same kVp as the Projection) and four sub-optimal cases (variations wherein the Flood-Field kVp is different from that of the Projection). Imaging performance was evaluated in terms of the uniformity, noise-power spectrum (NPS), and detective quantum efficiency (DQE) in Projection and DE image data. Phantom images were used to assess the contrast-to-noise ratio and perceived image quality of DE images processed under each correction scheme. **Results:** The results reveal a systematic degradation in the performance of the corrections as energy separation between the Projections and the Flood-Field increases. Sub-optimal correction schemes degraded imaging performance significantly: image uniformity degraded by a factor of 5-10; soft-tissue contrast degraded by ~13%; low-frequency NPS was significantly increased; and DQE was degraded by >10% at low- and mid-frequencies. **Conclusion:** The choice of Flood-Field correction scheme has significant impact on DE imaging performance. This study provides valuable guidance in the implementation of a high-performance calibration scheme for DE imaging. Deployment in a pre-clinical DE chest imaging system at our institution is underway.

WE-E-330D-05

Investigation of Imaging Performance and Acquisition Technique for a New Dual-Energy Chest Imaging System

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Purpose: A novel, high-performance, cardiac-gated dual-energy (DE) chest system is under development in our lab. This paper investigates the influence of key image acquisition technique parameters (viz., selection of kVp, filtration, and dose) on DE imaging performance. **Method and Materials:** Experiments were conducted on a DE imaging bench with a custom-built phantom containing simulated lung nodules of varying contrast. Performance was quantified in terms of nodule contrast-noise ratio (CNR^{DE}) in DE 'tissue-only' images. Low- and high-kVp were varied from 60-90 kVp and 120-150 kVp, respectively. Differential added filtration in low- and high-kVp projections was analyzed in terms of soft-tissue CNR^{DE} both theoretically across the entire Periodic Table (Z=1-92) and experimentally for specific material types (Al, Ce, Cu, and Ag). Allocation of dose (defined $A=ESD_{low}/ESD_{high}$) between low- and high-energy projections was analyzed at various levels of total entrance surface dose, ESD, over a broad range of allocation. **Results:** The results provide valuable guidance of technique selection for high-performance DE imaging. Optimal performance was achieved at a technique of [60/130] kVp, increasing soft-tissue CNR^{DE} by 32% compared to [90/120] kVp. Differential added filtration [0.2 mm Ce / 0.6 mm Ag] increased soft-tissue CNR^{DE} by 21% compared to the undifferentiated case ([1 mm Al / 1 mm Al]). Dose allocation was found to have significant influence on performance, with CNR^{DE} increasing by more than ~30% for A<1 compared to higher A>3 (with optima suggested in the range A~0.3-0.5). **Conclusion:** Knowledgeable selection of kVp pairs, differential added filtration, and dose allocation provide significant increase in the soft-tissue CNR of DE images compared to conventional or sub-optimal techniques. Quantitative theoretical and experimental evaluation demonstrates the importance of optimized acquisition techniques for high-performance DE imaging and guides the implementation of a novel DE imaging system under development for pre-clinical imaging trials.

WE-E-330D-06

Conceptual Examination of Conformal, Transparent, Indirect Detection, Active Matrix Mammographic Imagers

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Purpose: The recent development of techniques to create high-quality amorphous silicon (a-Si:H) at relatively low deposition temperatures enables the creation of active matrix arrays of thin-film transistors (TFTs) on very thin, flexible plastic sheets, rather than on thick, rigid glass substrates. In this presentation, an examination of the potential advantages and theoretical performance of indirect detection mammographic imagers based upon such arrays will be reported. Methods and Materials: Prototype active matrix arrays of thin-film transistors based on low-temperature a-Si:H and deposited on plastic substrates have demonstrated TFT performance essentially equivalent to that of devices produced with conventional a-Si:H. In addition, other prototype imagers have demonstrated that the incorporation of continuous photodiode structures can provide improved signal gain compared to arrays with discrete photodiodes at small pixel pitches. Techniques based on Monte Carlo simulations and cascaded systems analysis, parameterized by empirical information obtained from these early prototypes, have been employed to explore the performance of optimized imaging array designs operated under mammographic imaging conditions. **Results:** The excellent performance of transistors and photodiodes fabricated from low temperature a-Si:H, coupled with the incorporation of continuous photodiode structures, provides good signal and noise characteristics, even for sub-100 µm pitch designs. In addition, the flexibility and x-ray transparency of a thin plastic substrate allows for the possibility of conforming the shape of the detector to an arc and to position the scinitillator (and opposing active matrix array circuits) on the opposite side of the substrate relative to the x-ray source – leading to improvements in spatial resolution and DQE. **Conclusion:** Early investigations of the potential performance of indirect detection active matrix mammographic imagers based on low-temperature a-Si:H and fabricated on plastic substrates suggest that significant advantages would accrue from the development and implementation of such devices.

WE-E-330D-07

Empirical Studies of Polycrystalline Silicon-Based Flat-Panel Imagers Incorporating Pixel-Amplifiers

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Purpose: To investigate the potential of achieving significant improvements in the DQE performance of active-matrix flat-panel imagers at low fluoroscopic exposures and high spatial frequencies through incorporation of novel pixel architectures based on polycrystalline silicon thin-film transistors (TFTs). Methods and Materials: Detailed empirical studies have recently been performed on the signal and noise characteristics of a series of arrays incorporating poly-Si TFTs. These indirect detection designs involved three pixel architectures employing either a single TFT switch, a single-stage amplifier, or a dual-stage amplifier – along with a continuous photodiode structure. Determinations of MTF, NPS, and DQE, as well as of individual pixel properties (sensitivity, linearity, trapping, noise) were performed under fluoroscopic and radiographic conditions. Circuit simulations were also performed to explore the potential performance of these and other hypothetical array designs. **Results:** The studies indicate that the high mobilities of poly-Si lead to potential frame rates of at least an order of magnitude greater than those of conventional arrays with a-Si:H TFTs. In addition, the single- and dual-stage pixel-amplifier arrays demonstrate signal gain (~×10 and ~×25, respectively) very close to design expectations. Furthermore, empirical data taken from these early prototypes demonstrate a small, but non-negligible enhancement in signal-to-noise performance compared to that of similar arrays using conventional designs, as a result of pixel amplification and the use of repeated, non-destructive readout. Analysis based on these empirical results and circuit simulations indicates that, with circuit design optimization and improved TFT quality, further significant enhancement of performance should be possible. **Conclusion:** These results indicate that substantial improvements in DQE performance are possible through incorporation of poly-Si circuits in flat panel pixel designs. Factors limiting the performance of present designs will be described and future steps in the development of this technology will be discussed. This work is supported by NIH grant R01 EB000558.

Joint Imaging/Therapy Scientific Session — Valencia A

Correction Strategies

WE-E-ValA-01

Effect of Action Level and Uncertainties in Daily Imaging and Re-Positioning On the Distribution of Inter-Fraction Setup Uncertainty

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Purpose: To predict the post-correction probability distribution functions (PDFs) for inter-fraction setup uncertainty of individual patients who will undergo daily localization with an action level for setup correction. **Method and Materials:** An analytical method was developed to derive the PDF at a given action level assuming 1) a Gaussian distribution for the pre-correction setup uncertainty, and including, 2) uncertainty in online localization, and also 3) the uncertainty with which patients can be re-positioned. An interactive spreadsheet was developed to evaluate and graph the PDF, as well as its mean and variance. Plots of the mean and variance of the PDFs predicted at different action thresholds for user specified (or patient-derived) levels of the three input uncertainties above were used to develop practical action level rules. **Results:** When the variance of the localization uncertainty is the smallest of the three sources of uncertainty, there is an optimal action level that minimizes post-correction setup uncertainty. There is quantitative (and graphically demonstrated) improvement when σ_g^2, the sum of the variances of the localization uncertainty and re-positioning uncertainty, is less than σ_s^2, the variance of the pre-correction setup uncertainty. A practical rule is to set the action level to $\sigma_g(\sigma_s/\sigma_g)^{0.3}$ in these situations. The overlap of a resulting PDF with a Gaussian distribution with the same mean and variance is typically well over 90% when the action level is set according to this rule. **Conclusion:** The analytical method developed here is a useful tool to estimate the post-correction setup uncertainty at different action levels, and to set rules for clinical specification of the action level in cases where the precisions of localization and setup correction allow an improvement. It also permits evaluation of potential improvements in post-correction setup uncertainty associated with improved precision in daily localization and/or patient repositioning.

WE-E-ValA-02

Dosimetric Comparison of the No Action Level Alignment Protocol with Daily Alignment Techniques for Prostate Cancer

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Purpose: To compare the effectiveness of two off-line "No-Action-Level" (NAL) correction protocols with daily image-guided alignments using bony registration (simulating electronic portal image alignment), ultrasound, and CT for direct prostate target localization. **Method and Materials:** Ten prostate patients received 3 CT scans per week using an integrated CT-LINAC system immediately prior to radiotherapy (243 CT scans total). A clinical treatment plan was designed on the planning CT image using current clinical margins and copied onto the daily CT images. Two NAL protocols, based on CT measurements of the internal prostate shift relative to bony anatomy, were simulated for correcting the predicted internal systematic prostate shifts after 1 week or after 2 weeks of treatment. The NAL protocols were compared to three daily alignment methods, which simulated pelvic bone alignment, ultrasound alignment, and CT alignment. The dosimetric impact on target coverage for each scenario was reported. Reducing the planning margins to 3mm was also evaluated. **Results:** Daily CT scans are more accurate than daily ultrasound measurements for determining the prostate systematic positional shift, particularly in the anterior/posterior direction. The average minimum prostate dose was greatest with CT alignment (75.8Gy, $p<=0.028$), then with the two NAL protocols (both 74.Gy, $p<=0.017$), followed by ultrasound alignment (73.2Gy) and bone alignment (70.2Gy). For plans with 3mm margins, the average minimum dose was greatest with CT alignment (75.1Gy, $p<=0.007$), then with the two adaptive alignments (71.4Gy and 70.8Gy respectively, $p<=0.022$), followed by ultrasound alignment (68.4Gy) and

bone alignment (63.9Gy). **Conclusions:** An off-line NAL correction protocol for reducing systematic internal target shifts proved to be effective when performed after only one treatment week. The target dosimetric coverage from the NAL protocol was as good as daily ultrasound alignments but not as great as daily CT alignments. Using a 3mm planning margin exacerbated the differences in target coverage.

WE-E-ValA-03

Dosimetric Evaluation of Prostate IMRT Treatments Positioned Based On Cone-Beam CT

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Purpose: To evaluate the dosimetric consequence of 3D positioning verification for prostate IMRT treatment using CBCT. **Method and Materials:** Patients in this study were repositioned using 2D orthogonal radiographic images, taken prior to treatment to match 2D bone structures between the raidiographic and reference images. Following this, CBCT images were acquired, then the treatment was delivered without an additional shift. A verification plan, CB_{Treat}, was generated based on the CBCT to simulate the actual treatment achieved with positioning verification based on 2D bone structure match. A verification plan, CB_{Bone}, was created based on CBCT with the isocenter shifted to match 3D bone structures between CBCT and planning CT. A verification plan, CB_{Soft}, was created based on CBCT with the isocenter shifted to match 3D soft tissues between CBCT and planning CT. These three verification plans were created for 17 patients for the first treatment fraction and compared to the original plans. **Results:** The average dose coverage of prostate/seminal vesicle (SV) and dose to 30% of bladder/rectum showed very similar results for all three verification plans. Individual dose-volume histograms (DVH) displayed similar distribution for CB_{Treat} and CB_{Bone} of all 17 patients. However, DVHs of CB_{Soft} indicated that the coverage of prostate and SV was improved significantly for a few patients at the cost of increased dose to bladder/rectum. Current patient repositioning is limited to translational couch shift although we observed several patients with variations (e.g. prostate deformation due to rectal gas, bladder filling, volume variation) that could not be resolved by the couch shift. **Conclusion:** CBCT provides substantial bony and soft tissue information. It also reveals that the prostate is often deformed and simple translation correction will not improve the treatment accuracy. Therefore, customizing margin or adaptive therapy is essential for those patients.

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WE-E-ValA-04

The Effect of Deformation On IGRT of Prostate Cancer

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Purpose: To study how important it is to consider organ deformation under volumetric image guidance. Two questions were answered:1)how much residual misalignment exists after rigid-body image registration; and 2)what is the dosimetric impact if deformations is ignored by simply shifting the patient. **Methods:** 10 CTs were acquired on non-consecutive treatment days for 20 patients receiving radiation therapy of their prostate cancer under an IRB approved protocol. One physician contoured the prostate, rectum and bladder for all scans. To answer the first question, after rigid body registration of each image set acquired during the course of treatment with the planning CT, we measured the distance between the prostate boundaries along the three axes. For the second question, we copied the original plan with the shifts determined by rigid-body registration and compared with re-optimized plans based on the images of the day. Plan optimization was performed using the same dose and dose-volume constraints in the initial planning. **Results:** 10 patients were analyzed so far. Because these mismatches were measured after rigid-body registration, they were indicative of the prostate deformations during therapy. The mismatches varied widely among patients. The results were similar to that reported by Deurloo at al [1]. The largest deformation was seen in the A/P direction of patient 3, with a mean of 5.2mm and a standard deviation of 2.3 mm. For most cases with small target deformation, shifting the patient produces similar plans as re-optimization. In cases where there were substantial organ deformations, the plans resulting from translation were much worse than the re-optimized plan. **Conclusion:** Simply shifting the patient can be far from optimal. An IGRT scheme that can handle both translations and deformations is desired.

[1] Deurloo KE, et. al. Int J Radiat Oncol Biol Phys. 2005;61(1):228-38.

WE-E-ValA-05

Real-Time Tumor Tracking with a Feedback-Controlled Treatment Couch

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Purpose: To determine the feasibility of a moving treatment couch to compensate for real-time respiration-induced 3D tumor motion observed in patients. **Methods:** The couch dynamics were modeled as a critically damped second order system with dead time. The controller was modeled as a first order system to simulate the model dynamics mismatch between the couch and the controller. The feedback system was modeled as a closed-loop internal model control system and the parameters to describe the dynamics were obtained from previous feasibility studies. To determine the performance of this system, the average tumor trajectory data derived from 4D CT for 14 patients was considered. To simulate variations in normal intra-fraction respiration patterns for a given patient, distributions in amplitude and period were modeled and the residual tumor motion determined. The output of the control system was analyzed by evaluating the distribution of residual tumor motion. Furthermore, a detailed analysis of the residual motion as a function of tumor amplitude and velocity was conducted. **Results:** The mean 3D amplitude of uncompensated tumor motion was 7.1 ± 4.6 mm for 14 patients. Following feedback control, the mean residual tumor motion was 0.35 ± 0.20 mm with a mean respiratory period of 4 s. The residual motion was under 3 mm for all patients, for the range of time constants investigated. The response of the couch correlated linearly with instantaneous tumor velocity for the range of parameters used to describe the system dynamics ($R^2 = 0.98$). **Conclusion:** The treatment couch can be used to compensate for real-time tumor motion, given real 3D tumor trajectories. **Conflict of Interest:** Supported by 3DLine Medical Systems.

WE-E-ValA-06

A Real-Time MRI Guided External Beam Radiotherapy Delivery System

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Purpose: We present feasibility studies in support of a real-time MRI guided external beam radiotherapy delivery system currently under commercial development. **Method and Materials:** The system, (ViewRay Inc., Renaissance™), combines a low field open MRI scanner and a multi-headed ^{60}Co γ-ray IMRT unit equipped with multi-leaf collimators. It is designed so that the center of the field of view of the MRI and the isocenter of the radiotherapy unit coincide. The inherent compatibility of the units allows for the acquisition of fast ciné MRI simultaneous to radiotherapy delivery to assess intra-fraction organ motion. Computational feasibility studies were performed to investigate: the compatibility of the MRI and the ^{60}Co γ-ray IMRT unit; the impact of the MRI magnetic field on the dosimetry; and the feasibility of performing accurate heterogeneity dose computations with MRI data. **Results:** The ^{60}Co γ-ray IMRT unit was found not to significantly impact the operation of the MRI; the γ-ray IMRT unit is capable of producing high quality IMRT treatment plans; the MRI magnetic field eliminates contamination electrons and does not significantly perturb the dose distribution in lung, soft tissue, and bone; and accurate heterogeneity dose computations are possible employing only MRI data. **Conclusion:** Performing IMRT allows for the seamless integration with, and simultaneous operation of, an open MRI unit. **Conflict of Interest:** Research sponsored by ViewRay, Inc., Gainesville, Florida USA

WE-E-ValA-07

3D Dose Reconstruction with Megavoltage Cone-Beam CT and EPID Exit Dosimetry

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Purpose: The ability to reconstruct the delivered patient dose can help ensure that the integrated doses to important structures faithfully adhere to prescription. The objective of this work is to develop and test a 3D dose reconstruction procedure based on exit-dose measurements at treatment time and MV cone-beam CT. **Methods and Materials:** The proposed dose reconstruction method uses a Megavoltage cone-beam computed tomography (MVCBCT) image acquired on the treatment table prior to treatment, 2D portal images taken with an amorphous-silicon electronic portal imaging device (EPID) during treatment, and an independent validated dose calculation engine. The energy fluence obtained from the EPID is back-projected through the 3D MVCBCT image. A dose calculation engine based on a collapsed-cone convolution algorithm subsequently calculates the dose in each voxel. To test the model, a MVCBCT of a cylindrical solid-water QA phantom was acquired and the MVCBCT numbers mapped to appropriate attenuation coefficients. The phantom was then treated with a 5cmx5cm beam and a portal image acquired. During the treatment, a CC13 ion chamber and MOSFET detectors were used to measure the dose at 21 points to compare with reconstructed dose. A Pinnacle dose calculation using a conventional CT was also performed for comparison. **Results:** The mean difference between reconstructed and measured doses was –0.2% (standard deviation = 2.8%). The reconstructed dose in the inner regions of the cylinder differed less than 2% from the measured, although discrepancies of about 10% occurred at one point in the buildup region and at two other peripheral points. In comparison, the mean difference between Pinnacle calculations and measurements was –2.9% (standard deviation = 1.6%). **Conclusion:** Preliminary calculations of reconstructed dose demonstrated good agreement with experiments. Further refinement of the model and its application to clinical conditions are under investigation. **Conflict of Interest:** Research supported by Siemens.

Joint Imaging/Therapy Symposium Valencia B

Functional Imaging for Radiotherapy Guidance

WE-E-ValB-01

Advanced MR Imaging of Brain Gliomas: Implications for Radiation Therapy

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Brain gliomas are characterized by local infiltration and invasion of surrounding brain tissue. The limited responsiveness of these tumors to conventional modes of treatment underscores the critical need to improve our understanding about tumor heterogeneity through the use of in-vivo imaging, ultimately leading to the design and testing of new treatments.

Radiation therapy (RT) is a mainstay in the treatment of malignant brain tumors but there is significant room for improvement. Recent technical advances in the field of RT delivery allow for optimized, normal tissue sparing treatments with greater radiobiological effectiveness. However, these new powerful tools can only garner the greatest benefit if directed to the most appropriate (most aggressive and/or radioresistant) tumor region.

Magnetic resonance imaging (MRI) is considered the current imaging standard for brain gliomas and is widely used for target definition in RT. However, its information is limited to the morphologic tumor appearance. Radiographically, the presence of contrast enhancement on T1-weighted images indicates leakage of intravenous contrast into the tumor and signals a disruption of the blood-brain-barrier (BBB). This area is currently considered to reflect the most malignant area of the tumor whereas the hyperintensity on T2-weighted images is presumed to reflect a mixture of edema and tumor cell infiltration. However, it is increasingly accepted that this assumption is not fully justified due to the presence of contrast enhancement in areas of necrosis, the lack of contrast enhancement in certain regions of metabolically active tumor, and the inability of the T2 hyperintensity to distinguish between infiltration and nonspecific processes such as inflammation and reactive edema. Similarly, morphologic imaging is limited in the assessment of treatment effects/response.

New MR-based techniques have shown promise as a means of providing information on tumor metabolic characteristics and its biological behavior which ultimately will allow us to optimize, monitor, and assess therapeutic interventions beyond that currently provided by tools for the morphologic assessment of a malignant brain tumor. 3D Proton Magnetic Resonance Spectroscopy Imaging (MRSI) provides information on tumor cellularity and cell membrane breakdown, cellular energetics, neuronal activity, and hypoxia through its ability to distinguish signals from cellular metabolites such as choline, creatine, NAA, lactate, and lipid. Diffusion Weighted Imaging (DWI) provides additional information on cellularity, cell membrane permeability, intra- and extracellular diffusion, and tissue architecture, whereas Perfusion Weighted Imaging (PWI) provides insight into overall cerebral blood volume, tissue microvasculature and vessel permeability. The combination of these metabolic and physiologic modalities with standard anatomic MR modalities will enhance our current understanding of tumor heterogeneity and will provide guidance as to how to optimize current treatment approaches. Based on results from our current studies, we hypothesize that the continued failure of current targeted treatment approaches is in large part caused by insufficient knowledge about the tumor extent, its heterogeneity, and its biological behavior, resulting in directing some or all of the focal therapy to the wrong location.

In addition to assisting in image guidance for RT, these imaging tools hold promise for assessing and predicting therapeutic response and to help distinguish treatment effect and tumor recurrence.

WE-E-ValB-02

Functional Imaging for Radiotherapy Guidance - Quantitative Biological Imaging and the Oncologic Target

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Purpose: Biological imaging modalities are reviewed for their quantitative applications, contributions, and limitations in radiation treatment. Concepts are presented for biologically-matched dose distributions. **Method and Materials:** Quantitative use and assessment of anatomical and biological oncology images shows promise for identification and evaluation of targets for radiation treatment. Biological images, combined with anatomical images, contain digital information on the spatial distribution and intensity level of biological character representative for both cancerous and normal tissues. Quantitative aspects of "bioanatomic" images, for instance, from FDG PET-CT or MR spectroscopy, enable software processing and manipulation for target localization and delineation, assessment during treatment phase, and post-treatment evaluation. IMRT provides a method for selective targeting based on biology. **Results:** Bioanatomic imaging modalities include FDG PET, non-FDG PET-CT, MR spectroscopy, diffusion-weighted MR, MR perfusion, functional MR, magneto-encephalography (MEG), and others. Each modality/technique has finite spatial resolution, contrast (signal-noise-ratio), range of voxel intensity values, and sensitivity/specificity. Limitations for quantitative uses include spatial resolution, and "calibration" for validation of voxel intensities and image interpretation. Image digital file formats may be a challenge for certain images. Research opportunities include biology, physics, and imaging science work, and image-based clinical trials that combine bioanatomic images with advanced dose delivery. **Conclusion:** Contributions and limitations for quantitative uses of bioanatomical images in radiation treatment are reviewed, including digital characteristics of biological images. Potential benefits include a better understanding of tumor and normal tissue biology and treatment response, and radiation targeting that matches biological conditions.

Educational Objectives

1. Review characteristics of digital images and the task of image interpretation
2. Review signal origins relevant to tumor biology for selected imaging modalities
3. Describe the use of threshold parameters for biological radiation target delineation
4. Discuss concepts for biologically-matched radiation dose distributions
5. List research opportunities for basic science and image-based clinical trials

Conflict of Interest: Research sponsored in part by Varian Medical Systems and GE Healthcare.

WE-E-ValB-03

Challenges and Opportunities in Image-Guided Era

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Intensity-modulated radiotherapy (IMRT) is evolving rapidly; the radiation therapy community has begun to regard IMRT as the future standard of care, rather than as experimental or leading-edge treatment. The effectiveness and benefit of IMRT have been confirmed in multiple cancers, specifically in head and neck and prostate cancers. However, IMRT adoption rates vary widely and are impacted primarily by the learning curve for clinic staff, capacity, and physician's practice patterns. Because physicians must participate to a much higher degree in planning and quality assurance, their learning curves to acquire necessary knowledge and skills in cross section anatomical images are also steep. Image-guided radiotherapy (IGRT) or adaptive radiotherapy is an emerging radiation therapy treatment methodology that complements IMRT. IGRT takes tumor and organ motion into consideration and monitor this motion in a near real time mode to make sure radiation is being delivered to the tumor. Furthermore incorporating functional images into management decision-making has highlighted the future perspective of IGRT. However, to radiation oncology community the explosion of overwhelming technology has created challenges which include the lack of enabling tools to facilitate bench to bedside research, bridge knowledge gap, and improve quality and operational efficiency.

WE-E-ValB-04

Functional and Molecular Imaging for Radiotherapy Guidance

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Radiation therapy is an image-guided procedure whose success depends strongly on the image modality used for treatment planning and the level of integration of the available imaging information. Advancement in IMRT has provided an unprecedented means to produce highly conformable dose distribution while sparing sensitive structures, which calls for better imaging tools for tumor target definition and for the management of inter- and intra-fractional organ motion. In this talk we will summarize recent advances in functional and molecular imaging techniques and discuss various issues related to the integration of the newly emerged imaging data into radiation therapy planning. It is anticipated that the new imaging modalities will play an important role in radiation oncology practice and make significant impact in cancer diagnosis, staging, treatment planning, and monitoring of therapeutic response. The potential impact of biologically conformal radiation therapy (BCRT) or biologically guided radiation therapy (BGRT) will be discussed. Finally, issues related to the quality assurance of functional and molecular imaging and BCRT will also be addressed.

Educational Objectives:

1. Introduce the concept of functional and molecular imaging.
2. Illustrate the steps involved in integrating molecular imaging such as PET and MRSI into treatment planning process.
3. Introduce PET/MRI/MRSI and CT image fusion techniques (including deformable image registration).
4. Provide an overview on recent advances in PET/CT and MRSI, and update on the development of new PET tracers and data acquisition techniques.

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Therapy Scientific Session224C
Clinical Applications of IMRT

WE-E-224C-01

Dose Reconstruction Quality Assurance for Helical Tomotherapy

D Chase*, C Ramsey, R Seibert, Thompson Cancer Survival Center, Knoxville, TN

Purpose: To determine if the dose calculation accuracy is suitable for the daily dose verification of patient treatment; and develop quality assurance tests for dose reconstruction with a commercial dose reconstruction system. Methods and Materials: Dose reconstruction accuracy was evaluated using MVCT and kVCT images of three test phantoms: 1.) A Electron Density Phantom phantom (*Gammex*); 2.) A water-equivalent cylindrical phantom (*TomoPhantom*), and 3.) an anthropomorphic RANDO phantom. A parotid-sparing head & neck plan was created for the phantoms. Using the kVCT images, inverse treatment plans simulating clinical prostate and head & neck helical tomotherapy treatments were created. The phantom MVCT images were fused with the kVCT images using a co-registration algorithm. Planned-Adaptive software was then used to re-calculate the doses on the MVCT images. The kVCT-based and MVCT-based doses were then exported to the RIT113 Dosimetry System. Accurate dose reconstruction is dependent on the quality of the MVCT images used.As such, a genetic algorithm was developed to ensure proper image fusion and a principle component analysis was used to determine the most influential factors for image quality. **Results:** Based on the phantom results, the calculation accuracy of MVCT and kVCT images are typically within ±3% of each other. The greatest discrepancy occurs in the high-dose gradient regions, which is most likely due to slight alignment errors between the two dose files. PCA indicated a correlation with the person performing the machine warm-up and image quality. This was confirmed as MVCT dose reconstruction suffered due to an individual's error. **Conclusions:** Based on comparisons of calculated doses in phantom plans, the accuracy of using MVCT image data in dose reconstruction is typically within ±3%, subject to image quality. A process was developed for assessing the image contrast and resolution on a daily basis.

WE-E-224C-02

Investigation of Simple IMRT Delivery to Stage I Lung Cancer Patients with Significant Respiratory Motion Using Respiratory Gated CT Scans

B Reitz*, A Colonias, D Parda, M Miften, Allegheny General Hospital, Pittsburgh, PA

Purpose: To investigate the use of IMRT for the treatment of stage I lung cancer associated with significant respiratory motion using 4DCT data. **Method and Materials:** A 4DCT scan - covering a full respiratory cycle in 10 phases - of a patient with a 1.8 cm diameter lung cancer was used to design several static step-and-shoot IMRT plans. Three plans were designed: two using snapshots of the tumor (mid-inhale, full-exhale), one using the superposition of all phases. Because of the significant tumor motion (maximum excursion of 2.5 cm) the effect of different margins around the CTV were studied. To reduce interplay between the MLC movement and respiratory motion in an ungated delivery, the number of intensity-levels was minimized while maintaining coverage to the PTV and minimizing dose to OARs. **Results:** In this case-study five-field IMRT plans were generated using 18 MV photons delivering a total dose of 66 Gy in 33 fractions to the PTV. Plans based on snapshot scans of the lung only resulted in full coverage, if large margins (3 cm) were incorporated. All plans based on superimposed scans achieved full coverage, while allowing tight margins and minimizing the dosage to OARs. A small number of intensity-levels (3-5 per beam) were sufficient for PTV coverage, thereby reducing the risk of unwanted interplay effects between MLC movement and respiratory motion. **Conclusion:** Using snapshot free-breathing CT scans for treatment planning can lead to geometrical misses and underdosage of the target volume unless large PTV margins are applied at the expense of increased dose to OARs. Taking the superimposed CT scans of all respiratory phases for treatment planning ensures the full coverage of the tumor volume, without increasing dose to OARs. For this case-study only a small number of segments were needed, allowing the application of IMRT despite significant tumor motion.

WE-E-224C-03

Advanced Mixed Beam Radiotherapy for Breast and Head and Neck

C Ma*, J Li, S Stathakis, A Leal , F DuPlessis, J Fan, Y Chen, L Chen, S McNeeley, R Price, Fox Chase Cancer Center, Philadelphia, PA

Purpose: This work investigates advanced mixed beam radiation therapy (MBRT) treatment of breast and head and neck cancer using energy- and intensity-modulated electron (MERT) and photon (IMRT) beams. **Methods and Materials:** The new MBRT system consists of MLCs for both photon and electron beam modulation and associated software for dose calculation, treatment optimization, and beam delivery to ensure superior target coverage and normal tissue sparing. Accurate and efficient dose calculation tools for Monte Carlo based treatment planning, and effective treatment optimization and leaf sequencing algorithms for

efficient and accurate beam delivery for advanced MBRT have been developed with the use of existing MLCs. This technique is being implemented clinically for breast and head and neck treatment through pilot studies and clinical trials that are specially designed for dose escalation and hypofractionation. Partial breast treatment is also investigated using advanced MBRT as it is being developed. **Results:** MBRT uses IMRT to achieve lateral dose conformity and MERT for conformity in the depth direction, which provides excellent target coverage for treatments involving shallow target volumes such as breast and head and neck. Our preliminary results based on 76 patients showed that grade II skin complications were significantly reduced in a hypofractionated breast trial. The whole breast received 20 fractions of 2.25Gy and the tumor bed received an additional 0.55Gy/day concurrent electron boost. The elimination of 10% hot spots in the whole breast volume ensures the whole breast dose to be under 2.5Gy beyond which significant skin complications have been reported in the literature. **Conclusions:** A set of software and hardware tools have been developed for conformal radiation therapy of shallow targets with much improved target dose conformity and uniformity, adequate skin coverage/avoidance and significant reduction in the dose to the adjacent normal organs and critical structures.

WE-E-224C-04

A New CT Reconstruction Technique for Removal of Streak Artifacts Due to Metallic Dental Fillings and Implants for the Treatment of Head and Neck Cancer with Intensity Modulated Radiation Therapy

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Purpose: To remove or reduce the streak artifacts induced by metallic dental fillings and implants in CT images for head and neck patients treated with intensity modulated radiation therapy (IMRT). **Materials and Method:** A cylindrical phantom was constructed using tissue-equivalent plastic to simulate a human head. The phantom was filled with distilled water. A piece of 1 cm-wide half elliptic tissue-equivalent bolus was attached to a thin circular plastic plate inside the phantom to mimic the gingiva. Two human second molars with metallic fillings were implanted into the bolus on each side. The phantom was scanned on a GE LightSpeed CT scanner with a slice thickness of 2.5 mm. The acquired CT images were first decomposed into spatio-frequency components using a wavelet transform. The decomposition tree allowed us to examine and characterize different localized frequency information related to undesired artifacts. Once the spatio-frequency signatures of metal objects were modeled, the corresponding coefficients in the wavelet domain were thresholded using a dynamic thresholding scheme. The thresholded images gave metal objets, which were then superimposed on a neighbor slice. New data were generated by re-projecting the original slice and superimposed slice. The final image was reconstructed with no or reduced image artifacts due to dental fillings and implants. **Results:** Comparison of original images to reconstructed images indicates that the streak artifacts were either completely removed or significantly reduced. The structural details near the metal objects were clearly identifiable. The image quality was sufficient for target delineation in IMRT treatment planning. **Conclusions:** The proposed technique can greatly reduce the streak artifacts induced by metallic dental fillings and implants without sacrifice of spatial resolution. The technique has the potential to significantly improve the accuracy of target and critical organ delineation and dose calculation in the head and neck IMRT treatment planning.

WE-E-224C-05

Uncertainty Analysis of Risk of Secondary Fatal Malignancies From Radiotherapy Treatments Including IMRT

S Kry*, D Followill, R White, M Salehpour, UT MD Anderson Cancer Ctr., Houston, TX

Purpose: Radiation away from the treatment field may induce secondary cancers in long-term survivors. Risk estimates have received increased attention with the increase in out-of-field dose associated with IMRT. However, uncertainty in these risk estimates were not previously established, which has left unresolved the significance of these risk estimates. This work examines the uncertainty in the absolute risk estimates, as well as uncertainties in the ratio of risks between treatment modalities. **Method and Materials:** Effective dose equivalents and estimated risks were taken from the literature for several treatment modalities including IMRT at 6, 10, 15, and 18 MV and conventional therapy. The most recent risk estimates (5.75%/Sv) along with uncertainties in this risk estimate and uncertainties in the dose-response model were considered in generating 90% confidence intervals for the absolute risk estimates and ratio of the risk estimates. **Results:** The absolute risks of fatal secondary malignancy were associated with very large uncertainties, which precluded distinguishing between the risks for the different treatment modalities considered. However, a much smaller confidence interval existed for the ratio of the risk. Because of the confidence intervals generated, an effective dose equivalent difference of 50% resulted in a statistically different ratio of the risks. Such differences were observed between some of the treatment modalities considered including 6MV as compared to 18MV IMRT. **Conclusion:** While no statistically significant difference existed in the absolute risk estimates of the treatment options examined in this study, the ratio of the risks was found to yield statistically significant differences between some treatment modalities considered.

WE-E-224C-06

Differential Smoothing IMRT Planning for Head and Neck Cancer Patients with Mediastinal Involvement

D Schofield*, R Tishler, L Court, Dana Farber/Brigham and Women's Cancer Center, Boston, MA

Purpose: Head and neck cancer patients with mediastinal involvement present a planning challenge. The superior fields are ideal for IMRT but possible interplay effects between leaf and mediastinal motion makes IMRT less desirable for the inferior fields. A new, differential smoothing IMRT technique is compared to matched and extended field IMRT plans. **Materials and Methods:** The differential smoothing IMRT technique treated the superior portion of the target with 7 fixed, low smoothing rate (LSR) beams while the inferior portion was treated by 3-4 highly smoothed, fixed beams with an overlap region. All beams existed in a single IMRT plan and were optimized simultaneously. This technique was used to plan treatments for three head and neck cancer patients with mediastinal involvement. These patients were also planned using two alternative techniques: (1) A matched field technique, with conformal radiation therapy used for the inferior portion, and an LSR IMRT plan used for the superior portion; (2) An extended field LSR IMRT plan treating the full extent of the disease. The plans were compared dosimetrically. **Results:** The differential smoothing technique provided homogenous, continuous coverage throughout the target volume while the matched field plan demonstrated discontinuous coverage in the match region. The extended field IMRT plan had coverage comparable to the differential smoothing plan. However, patient and leaf motion could compromise coverage in practice. The average MLC leaf opening in the inferior differentially smoothed beams was 1.5-2 times greater than the average opening in any of the LSR beams (1.55cm for LSR beams verses 3.04cm for highly smoothed beams) thereby potentially reducing the impact of patient motion. Lung DVH's were similar for all three techniques. **Conclusion:** The differential smoothing technique offers continuous, more homogenous coverage than the matched field method and is probably less susceptible to patient motion than the extended field technique.

WE-E-224C-07

Image-Guided Helical Tomotherapy for Localized Prostate Cancer: Technique and Initial Clinical Observations

C Ramsey, D Scaperoth, R Seibert, D Chase, C Harris*, Thompson Cancer Survival Center, Knoxville, TN,

Purpose: The purpose of this study was to develop a technique for daily CT based IGRT, and to report clinical observations on treatment planning, imaging and delivery based on the first two years of experience. **Method and Materials:** Patients with previously untreated stage T1 through T3 biopsy-proven adenocarcinoma of the prostate were considered eligible for treatment with daily CT guided helical tomotherapy. The prostate was targeted daily using megavoltage CT (MVCT) images that were fused with treatment planning CT images based on anatomical alignments. All patients were treated at 2 Gy per fraction to 76 to 78 Gy (mean 76.7 Gy). **Results:** Thirty-three prostate patients were planned, imaged, and treated as part of this study for a total of 1266 CT guided fractions. The prostate, rectum, bladder, femoral heads, and pubis symphysis were visible in one or

more slices for all 1266 MVCT image sets. The typical range of measured prostate displacement in this study was 2-10 mm (3.4 mm standard deviation) in the anterior-posterior direction, 2-8 mm (3.7 mm standard deviation) in the lateral direction, and 1-6 mm (2.4 mm standard deviation) in the superior-inferior direction. The obese patients in this study had a substantially larger lateral variation (8.2 mm standard deviation) due to mobility of the external skin marks. **Conclusions:** A technique has been developed, and clinical implemented for daily MVCT based image-guided radiation therapy. The level of conformal avoidance increased with treatment planning experience, and the level of conformal avoidance can be greater than fix-gantry based intensity modulation.

Therapy Symposium Room 224 A
The Role of External Beam in Brachytherapy

WE-E-224A-01
The Best of Both Worlds: Taking Advantage of Brachytherapy and External Beam Radiotherapy

Y Yamada*, Memorial Sloan Kettering Cancer Center, New York, N.Y.

Introduction. Brachytherapy and external beam radiation represent opposite ends of the inverse square dose fall off spectrum. Brachytherapy is well suited for the delivery of conformal localized high dose radiation. While external beam radiation is well suited for conformal local and regional treatment, it is able to treat larger volumes in comparison to brachytherapy. This paradigm fits well with the natural history of many malignancies to provide maximal tumor control probability while minimizing normal tissue complications.
Methods and Materials. Two examples of combining brachytherapy and external beam radiation which illustrate the brachytherapy/external beam radiation therapy paradigm will be presented: The combination of high dose rate (HDR) brachytherapy and intensity modulated radiation (IMRT) for the definitive management of localized prostate cancer, and the use of a Yttrium 90 dural plaque in conjunction with image guided IMRT for vertebral body chordomas with significant epidural disease.
Results: HDR prostate brachytherapy and IMRT provides a very high level of disease control with only minor toxicity for patients with localized prostate cancer. This is likely due to careful treatment planning to minimize dose to critical structures such as the rectum and urethra while delivering a very high biologic effective dose to tumor bearing tissue. Similarly, Yttrium 90 dural plaques are able to deliver a very high dose of radiation to the dural surface, while underlying spinal cord will receive less than 5% of the prescribed dose. This will allow for a extremely high dose of radiation to be given to the planning target volume and increase the tumor control probability. **Conclusions:** Both brachytherapy and IMRT have inherent physical advantages that can be utilized to improve the therapeutic ratio of radiation therapy. Particularly in the management of tumors where a dose-control relationship exits situated near dose sensitive structures, this paradigm is especially important.

WE-E-224A-02
The Role of External Beam in Brachytherapy

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Combination of permanent low dose-rate interstitial implantation (LDR-BRT) and external beam radiotherapy (EBRT) has been used in the treatment of clinically localized prostate cancer. Patients treated with this regimen initially receive an I-125 implant prescribed to 110 Gy followed, two months later, by 50.4 Gy in 28 fractions using intensity modulated external beam radiotherapy. While a high radiation dose is delivered to the prostate in this setting, the actual biologic dose equivalence compared to monotherapy is not commonly invoked. I shall describe *methodology* for obtaining the fused dosimetry of this combined treatment and assigning a dose equivalence which in turn can be used to develop desired normal tissue and target constraints for biologic-based treatment planning. Furthermore, I shall argue that LDR-EBRT treatments, when properly designed, may confer significant advantages in terms of: a) escalating the dose without normal tissue penalties, b) avoid the question of organ motion, and c) decrease significantly the size of the PTV.

WE-E-224A-03
Optimizing Fractionation Or Dose Rate for Prostate Cancer Radiotherapy

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For most tumors, increasing the number of fractions / lowering the dose rate, results in an improved therapeutic ratio between tumor control and late sequelae. Why might this not be true for prostate cancer?

1. The basis for the difference in fractionation response of tumors and normal tissues is generally related to the fact that there is a larger proportion of cycling cells in tumors.
2. Back in 1999, various authors reasoned that prostate tumors might not respond to changes in fractionation in the same way as other cancers, as they contain smaller fractions of cycling cells – rather that they might respond like a late-responding normal tissue. If so, much of the rationale for using many fractions, or using LDR, would disappear.
3. A first estimate of α/β for prostate cancer was made in 1999, by comparing results from external beam RT (EBRT) with those from brachytherapy. The estimate was 1.5 Gy [0.8–2.2 Gy], similar to α/β values for late-responding normal tissues (~3 Gy).
4. If the α/β value for prostate cancer is indeed similar to that for the surrounding late-responding normal tissue, one could use many fewer fractions, or HDR, and yet, by choosing the right dose, have
   - Comparable tumor control and late sequelae to conventional fractionation
   - Reduced early urinary sequelae
   - Patient convenience
   - Financial / resource advantages
   - Potential for biologically-based individualized treatments
5. Various other groups used the same approach (comparing EBRT with brachytherapy) for estimating the α/β ratio, and got similar results. However the weakness inherent in this comparative approach (different dose distributions, different treatment times, different dose rates, different RBEs, etc) has led to much controversy.
6. Subsequently an analysis was performed which avoided many of these pitfalls, in which EBRT + a 2-fraction HDR boost was compared with EBRT + a 3-fraction boost, all done with the same technique at the same institution. The result was 1.2 Gy [0.03–4.1 Gy], again comparable with α/β values for late-responding normal tissues (~3 Gy), and confirming that hypo-fractionation or HDR are promising subjects for clinical trials of prostate cancer RT.
7. The arguments presented above really relate to the α/β value for prostate cancer *in relation to that for the relevant late-responding normal tissue.* Just what is the appropriate α/β value for late rectal complications? Evidence from animal studies is that $\alpha/\beta>4$ Gy for late rectal sequelae. This high value for late rectal damage is now supported by clinical results, which also suggest that much late rectal injury is actually consequential of early effects, and thus a high α/β value is not unreasonable.
8. If, then, the α/β value for prostate cancer is actually *less than* that for the surrounding late-responding normal tissue, now hypofractionation or LDR, at the appropriate dose, would yield
   - increased tumor control for a given level of late complications, *or*
   - decreased late complications for a given level of tumor control.
9. The 2005 bottom line is that the long-term clinical results to date for prostate hypofractionation do not give any indication of increased late sequelae compared with conventional fractionation – despite the fact that most of these results come from the pre-IMRT era.

Educational Objectives:
There is a great deal of controversy in the literature about the most appropriate value of the α/β ratio for prostate cancer. Hopefully the audience will leave with a better understanding of 1) why this is, and the 2) what is its significance in terms of optimizing prostate cancer radiotherapy?

WE-E-224A-04
Potential and Challenges of Integrated Brachytherapy-IMRT Planning

J Williamson*, Virginia Commonwealth University, Richmond, VA

Combinations of external-beam radiation therapy (EB) and brachytherapy (BT) and have been used for many years. Conventionally, the EB and BT

components are planned independently and limited to combinations of doses and dose-time-fractionation patterns that have been directly validated by clinical outcome studies. Ongoing research in radiobiological modeling, deformable image registration, and quantification of dose delivery uncertainties has the potential to provide the scientific foundation for truly integrated EB-BT planning that could significantly improve clinical outcomes. First, the complementary strengths and weaknesses of BT and highly conformal EB methods, such as intensity-modulated radiation therapy (IMRT), will be reviewed. Both IMRT and BT can support high dose conformality. IMRT can treat large surgically inaccessible target volumes with relatively homogeneous dose distributions. Where BT can be surgically realized, large dose fractions can be delivered with much higher geometric precision than with current IMRT delivery techniques. Next, clinical settings where integrated BT-IMRT can have benefit will be reviewed. One example is definitive treatment of cervical cancer in which IMRT is used to compensate for primary tumor underdosing or normal tissue overdosing by the intracavitary BT insertions as well as for conformal treatment of the pelvic lymph nodes. Finally, the scientific and clinical challenges to integrated BT-IMRT will be reviewed. For example, in high dose-rate (HDR) interstitial BT of the prostate combined with IMRT whole pelvic irradiation for intermediate risk disease, a major source of dose-delivery uncertainty is the conversion from physical-to-isoeffective dose needed to account for differences in fractionation.

THURSDAY, AUGUST 3

Imaging Continuing Education Course — Room 330 A

CE: Breast Imaging Physics and Technology - IV

TH-A-330A-01

Optimizing Mammography Image Quality and Dose

E Berns*, Northwestern University Feinberg School of Medicine, Chicago, IL

Digital mammography is quickly becoming the technology of choice for breast imaging with several FDA-approved systems already available and more on the way. Digital detectors in mammography have different characteristics than the traditional screen-film systems and care should be taken when implementing these systems into a clinical environment. This lecture is going to discuss the practical issues for the medical physicist who wants to learn how to optimize dose and image quality in mammography primarily focusing on full-field digital mammography systems (FFDM). The lecture will be broken into several parts. The first will review currently available FFDM equipment including an overview of automatic exposure modes, quality control pertaining to image quality and dose, and system technique selection. The second part will discuss techniques for measuring dose and image quality in FFDM. The third part will discuss factors affecting image quality and dose and ways to optimize FFDM systems in a clinical environment.

Imaging Continuing Education Course — Room 330 D

CE: PET Physics and Technology - IV

TH-A-330D-01

PET - Radiation Safety and Shielding Requirements

J Anderson*, UT Southwestern Medical Ctr at Dallas, Dallas, TX

PET/CT imaging is a relatively new imaging modality that has become standard-of-care for the diagnosis and staging of many medical conditions. This has led to the widespread construction of new PET/CT installations. The design of such facilities, involving aspects of both nuclear medicine and radiology practice, presents some novel problems to the medical physicist. The recently issued report of AAPM Task Group 108, "PET and PET/CT Shielding Requirements," addresses these difficulties and provides the designer with basic information needed for this work. The information from the report as well as the workflow in PET/CT facilities, the nature of the studies that are performed, the way in which to estimate patient workloads, and the computational approaches to radiation shielding design for high-energy photon emitters will be discussed. Specific examples for the design of PET/CT shielding will be given.

Educational Objectives:

1. To discuss the recently released report of AAPM Task Group 108 on PET and PET/CT Shielding Requirements and provide some specific examples of the methods described in that report.
2. To provide an overall understanding of the workflow, exam procedures, patient workloads, and radiation safety practices at PET and PET/CT imaging facilities.
3. To review the approaches and necessary data for calculating shielding requirements for PET isotopes.

Imaging Continuing Education Course — Valencia A

CE: Medical Imaging Informatics - IV

TH-A-ValA-01

The Value Proposition of the Physicist in Informatics

P Nagy*, Univ Maryland School of Medicine, Baltimore, MD

There exists today a vacuum in the knowledge to transform medicine with information technology (informatics). Many diagnostic physicists today get pulled into their institution's PACS implementation willingly or not and find themselves trying to provide informatics leadership. For those physicists who are interested, aiding a facility with informatics can be very rewarding. There is a strong affinity between the informatics skill set and the role of diagnostic physics in the way we bridge the worlds of science and technology with medicine. Many of the leaders of the Society of Imaging Informatics in Medicine (SIIM, formerly SCAR), are diagnostic physicists. There is an opportunity of growth for the profession to provide leadership in the changing face of medicine. A subcommittee on Imaging Informatics has been established by the AAPM to understand this opportunity. The views expressed in this talk are my own and do not necessarily reflect the opinions of the committee.

We will try and present a roadmap for those physicists who are being called in to fill the informatics roles of their department or are interested in expanding their clinical tool set to include informatics. Most physicists trained today have a solid grounding in computer science. In addition to a good comprehension in computer science, an informaticist needs to know about systems management, systems integration, and project management.

Systems management includes the information technology principles needed to ensure smooth operations of a large IT service such as PACS. This includes availability monitoring, change management, failure mode effects analysis, problem management, performance monitoring, disaster recovery, and continuity management to name a few. A physicist should not be a PACS administrator, but instead be the person to train the PACS administrators and provide the oversight and strategy to allow the facility take advantage of information technology. This is identical to our role in working closely and training technologists in image quality. The majority of PACS administrators are at the same educational level of imaging technologists.

Systems integration is a crucial part of any IT project implemented today. The need to understand the role and value of open standards based integration such as DICOM, HL7, and IHE is critical in helping to set the vision of how the facility will interoperate with the enterprise.

Project management and good communication skills are very useful in helping to coordinate large initiatives such as PACS that requires many parties to work in concert. This typically entails take the strategy view and keeping it on track at the tactical level.

Also discussed will be how some basic informatics skills can help you do your job better as a physicist. There are open source tools available that can enable you to setup DICOM research repositories as well as help you automate some of the quality control role of the department to monitor image quality and dose. There is an immense amount of data that can be mined from DICOM data with some basic tools. Film printer and monitor calibration data can also be remotely monitored and aggregated with simple network management protocol (SNMP) agents.

In conclusion the physicist is positioned to be a technology advocate for physicians, and extending this to include informatics can be very rewarding. There could even be some benefit to recognizing informatics in the curriculum of diagnostic physicists.

Learning objectives:

1. Understand the opportunity of imaging informatics for medical physicists
2. Discuss the overlap in the skill sets between informaticists and physicists
3. Discuss the pros and cons of being involved in clinical informatics projects like PACS
4. Discuss the benefits and problems of being a dual role diagnostic physicist.
5. Identify additional areas a physicist should pursue to play the role of an informaticist:
    - Principles of Systems Management
    - Systems Interoperability and Data Integrity
    - Project Management

Imaging Continuing Education Course Valencia B
CE: Computed Tomography Physics and Technology - IV

TH-A-ValB-01
ACR CT Accreditation
D Pfeiffer*, Boulder Community Foothills Hospital, Boulder, CO

The American College of Radiology accreditation program for computed tomography, introduced in 2002, is quickly gaining in popularity. It has established minimum standards for dose and image quality. Since the inception of the program, the scanners themselves have continued to evolve in complexity and capability. Medical physicists are required by the program to perform an annual survey of each scanner and are increasingly called upon to provide assistance with dose/image quality analyses. Thus, the involvement of medical physicists in CT is necessarily increasing.

To provide optimal support for facilities in the accreditation program, it is necessary that physicists be fully aware of the requirements of the program. To that end, the essentials of the program will be briefly reviewed, including personnel requirements. The quality control component of the program will be discussed, with special attention given to the annual medical physics survey. Technologist testing requirements will also be discussed.

The medical physicist can have a positive impact on the phantom images submitted as part of the accreditation process, so the site scanning instructions will be reviewed in detail, with comments made regarding common pitfalls.

With the national awareness of radiation doses in CT, this area is perhaps where the physicist can have the largest impact clinically. In this lecture, the ACR accreditation program dosimetry requirements will be presented, including a discussion of common pitfalls and corrective measures.

The education objectives of this program are to become familiar with:
1. the general requirements for the ACR CT accreditation program
2. the role and responsibilities of the medical physicist
3. the image quality and dose measurements required by the program
4. how to calculate CTDIw, CTDIvol, Dose Length Product and Effective Dose

Therapy Continuing Education Course Room 224 A
CE: QA for Imaging Systems Used for Planning (CT, PET, MR)

TH-A-224A-01
QA for Imaging Systems Used for Planning (CT, PET, MR)
S Mutic*, Mallinckrodt Inst of Radiology, Saint Louis, MO

Imaging for radiation therapy treatment planning has different goals than diagnostic imaging. Quality assurance (QA) of imaging devices (CT, PET, MR) which are used for radiation therapy imaging will therefore have different or additional goals compared to QA for diagnostic imaging purposes. Use of PET and MR imaging in radiation therapy is constantly increasing and reliable performance of these imaging modalities is important to avoid potentially significant errors.

Quality assurance for CT scanners used for radiation therapy scanning is relatively well established and defined. This process remains to be adequately defined for PET and MR scanners that are used for treatment planning. Evaluation of image quality of CT, PET, and MR scanners is generally adequately addressed by procedures which were established for diagnostic imaging. Design of QA protocols for radiation therapy scanning should be founded on procedures which are used for diagnostic imaging. Evaluation of mechanical accuracy and image spatial integrity is unfortunately not a major concern in diagnostic imaging and these parameters are often not sufficiently addressed in diagnostic QA protocols. All three imaging modalities have multiple potential sources of spatial and geometric errors and understanding of these parameters is necessary for design of an effective quality assurance program. The design of QA programs for these devices will be affected by the location of individual scanner and distribution of its utilization for diagnostic and radiation therapy imaging. Scanners which have dual purpose (diagnostic and treatment planning imaging) should have a QA program designed jointly by diagnostic and radiation therapy physicists to ensure that the program meets the needs of both groups.

The quality assurance for these imaging modalities in the radiation therapy goes beyond the QA of the scanners and should include evaluation of implementation of images in the treatment planning process. This should include evaluation of data transfer, image registration, potential degradation in image quality, image distortions, and evaluation of process for delineation of tumor and normal structure volumes. MR and PET images can contain biologically active regions which may not correlate with any readily visible anatomic features. Correct identification and use of these regions in the treatment planning process should be a major concern of the QA program.

This lecture will provide an outline and description of QA program for CT, PET, and MR scanners used in radiation therapy. The fundamental goals of such program will be described and information which can be used for establishment institution specific QA programs will be provided.

Educational Objectives:
1. Describe goals of QA programs for CT, PET, and MR scanners used for radiation therapy imaging
2. Describe QA process for individual imaging devices
3. Describe a concerns for verification of correct implementation of these imaging modalities in the treatment planning process

Therapy Continuing Education Course Room 224 C
CE: Daily Localization - IV: Ultrasound and Implantable Devices

TH-A-224C-01
Long Term Clinical Experience Using Ultrasound Alignment
S McNeeley*, Fox Chase Cancer Center, Philadelphia, PA
The use of ultrasound localization in radiotherapy has been in wide clinical use since the late 90's. It is the one of the first imaged guided radiotherapy (IGRT) systems to be widely used. The most common site of localization has been the prostate using a transabdominal approach. The technique makes use of treatment planning contour volumes with their associated isocenter overlaid on spatially localized ultrasound images. The ultrasound images are localized to the linac isocenter using various methods that include: a robotic arm, inferred stereotactic cameras, or various optical tracking methods. The difference in position between the overlaid contours and the observed ultrasound structures provides the three dimensional patient correction.

Ultrasound localization has shown to be an efficient method of alignment but it does have limitations. Ultrasound images are often difficult to interpret. For prostate, the transabdominal approach takes advantage of the increased resolution when imaging through the bladder, typically positioned anterior and superior to the prostate. When patient's bladders are empty, degradation in prostate imaging typically occurs. Often, large patients necessitate using lower frequency ultrasound, which also degrades the image quality. Large patients may also limit the ability to perform a transabdominal ultrasound with the presence of a pannis. Additionally, the operator's capacity to capture and interoperate ultrasound images can vary, limiting the quality of the alignment.

This lecture will touch on some of the techniques used to improve ultrasound alignment quality. These techniques were developed at an institution where over 100,000 ultrasound alignments have been performed since 1998. Also, the results from several clinical studies will be presented. These include abdominal pressure effects, procedural changes improving alignment quality, comparison with daily CT, and complication rates of a hypo-fractionated prostate protocol using ultrasound alignment.

Educational Objectives:
1. Techniques in improving ultrasound image quality during alignment.
2. Understanding the limitations in performing ultrasound alignment.
3. Procedural changes that can improve alignment quality.

TH-A-224C-02
Daily Localization -4: US, Calypso and AlignRT
J Balter*, Univ Michigan, Ann Arbor, MI

Two technologies have been recently applied to commercial product development for localization and monitoring of treatment. Electromagnetic tracking, quite mature in aerospace and surgical guidance, has evolved to development of implantable markers. Video-based surface mapping systems have been applied to a product that rapidly extracts the anterior surface of a patient as an aid to localization and motion measurement.

These new systems show dramatic promise as aids to initial setup. Precision on the order of 1-2 mm has been described for both technologies. These systems act as surrogates for tumor localization inferring that either a) the patient's skin or b) implanted fiducial locations can be correlated to tumor position. For the prostate, implanted fiducials have shown acceptable accuracy when properly placed. For surface imaging, targets near/at the surface (e.g. breast cancer) should work very well. For other body sites, investigations are ongoing.

In addition to rapid setup, the monitoring capability of these systems presents a paradigm that has been extremely limited to date in treatment rooms. The ability to more directly infer target position to aid in gating and tracking, especially without the use of additional ionizing radiation to the patient, may have dramatic impact on targeting accuracy.

This lecture will overview these technologies, and will discuss core measurements to establish accuracy and compatibility in the radiotherapy environment. Procedures for use will be outlined, as well as potential limitations of these systems

Educational Objectives:
1. Understand the operating principles of electromagnetic and surface localization
2. Overview systems using these technologies
3. Understand critical issues for commissioning of such systems

Therapy Continuing Education Room 230A
Course
CE: Heterogeneity Corrections in the IMRT Era

TH-A-230A-01
Heterogeneity Corrections in the IMRT Era
N Papanikolaou*, Cancer Therapy and Research Center, San Antonio, TX
Intensity modulated radiation therapy (IMRT) has revolutionized the treatment planning process. We are now able to produce treatment plans for complex target shapes that have remarkable dose conformity while respecting the tolerance doses to critical structures. Although the emphasis has been given in the implementation of faster, more efficient, and more comprehensive optimization algorithms to solve the inverse problem, little has been done in the dose calculation aspect of the planning process. The convolution/superposition algorithm is the most popular photon dose engine used in treatment planning, while the Monte Carlo algorithm although available, remains a futuristic option.

In this presentation we will discuss the algorithms that have historically been used for treatment planning with photon beams with emphasis on the convolution and Monte Carlo based methodologies and their application in IMRT planning. Clinical examples will also be presented to demonstrate the use and outcome of dose calculations in homogeneous and heterogeneous media.

Educational Objectives:
1. Review of dose calculation algorithms for photon beams
2. Demonstrate the effect of dose algorithm selection in IMRT planning

Imaging Continuing Education Room 330 A
Course
CE: Radiation Safety and Risk Management - IV

TH-B-330A-01
Shielding Design Workshop: CT
M Martin*, Therapy Physics, Inc., Bellflower, CA

The application of the structural shielding design techniques and goals as outlined in NCRP Report 147: *Structural Shielding Design for Medical X-ray Imaging Facilities* (2004) will be the basis for this practical course. The wide variety of facilities installing
CT imaging equipment requires the medical physicist to consider an array of radiation protection concerns for the installation of these units. To meet the challenge of maintaining construction costs to a minimum while providing adequate radiation shielding protection requires the physicist to utilize all available materials to reduce radiation exposure to surrounding personnel and the public. Estimating future workloads as well as considering current workloads for uses of CT scanners as the ability to perform many more scans more quickly can present challenges. Practical examples of implementing multi-slice scanners with a variety of imaging purposes into facilities with a wide variety of existing shielding materials will be explored in this course.

Educational Objectives:
1. Understand the methods of structural shielding design to use for sing and multi-scan CT scanners.
2. Understand the radiation exposure limits for surrounding areas occupied by the public and occupational personnel.
3. Understand methods to predict applicable workloads for various types of facilities and CT scanners.

Imaging Continuing Education Room 330 D
Course
CE: Radiography Physics and Technology - IV

TH-B-330D-01
Quality Assurance Procedures for Digital Radiography
D Peck*, Henry Ford Hospital System, Detroit, MI

The use of digital radiography is becoming the normal form of image capture replacing film. With film there are numerous Quality Assurance (QA) procedures that have been developed that cover the film processor, retake analysis, patient dose and overall system image quality. The QA procedures for digital systems are just now being developed. Since the digital detector technologies vary and with variations in image processing methods it may seem difficult to develop standardized QA procedures. Yet the endpoints of optimized image quality and minimized patient dose need to be obtained. Therefore the Physicist needs to use the knowledge of the detector characteristics and processing methods as tools to maintain QA on digital systems. These procedures need to be rigorous enough to provide QA, yet they must be flexible enough to work for different detectors, processing methods and system applications. This lecture will provide an overview of the testing procedures for digital radiographic systems and suggest procedures that can be used to provide QA in digital radiography.

Educational Objectives

1. Review detector testing procedures used to assess digital systems
2. Review QA procedures used in radiography and relate these to digital technologies
3. Suggest QA procedures that can be used to evaluate digital systems

Imaging Continuing Education Course Valencia A
CE: Fluoroscopy Physics and Technology – IV

TH-B-ValA -01
Managing Patient Dose and Staff Exposure in Fluoroscopic Procedures
K Strauss*, Children's Hospital, Boston, MA

(No abstract provided)

Imaging Continuing Education Course Valencia B
CE: MRI Physics and Technology - IV

TH-B-ValB-01
Optimizing MR Imaging Procedures: The Physicist as a Consultant
L Lemen*, Univ of Cincinnati, Cincinnati, OH

Every MR system has its strengths and weaknesses, often varying tremendously both within and between the various system designs. Added to that, each site will have its own priorities and styles of use of their system. For an MR physicist to best assist in optimizing imaging procedures, it is extremely important for that individual to be both well-versed in basic MR physics, and to be able to recognize (and understand) the impacts and trade-offs of the technology in a large variety of imaging situations. The physicist should be able to determine and evaluate problems in patient images as well as phantom tests.

For this presentation, the basic relationships between MR imaging parameters will be reviewed with an emphasis on their implementation in common clinical protocols. Examples of how they are adapted for specialized procedures will then be given to demonstrate trade-offs between contrast requirements; imaging speed; spatial resolution; geometrical accuracy, and patient safety issues. How specific field strength and gradient configurations affect these options will also be examined. Differences in RF coil properties will be discussed from the perspective of optimizing applications for a facility.

Educational Objectives:
1. Understand the primary tissue contrast characteristics of the standard clinical sequences; methods of selective elimination of tissue signals; and the role of exogenous agents to alter contrast.
2. Know how to consider the interactions between SNR, spatial resolution and imaging speed and how their combined effects determine image quality for a variety of clinical situations.
3. Understand circumstances under which patient physiology and system configuration may require modification of image acquisition parameters to achieve optimal image quality.

Therapy Continuing Education Course Room 224 A
CE: QA for Linacs and MLC used for IMRT

TH-B-224A-01
QA for Linacs and MLC Used for IMRT
P Xia*, UC San Francisco, San Francisco, CA

Intensity-modulated radiotherapy (IMRT) has become a part of our routine treatment for external beam radiotherapy. Most quality assurance procedures set for linear accelerators and multi-leaf collimators (MLC) have been designed for conventional external beam radiotherapy. With IMRT, radiation portals are often irregular, small, off-center, and abutting in the middle of the target volumes, which require specific IMRT QA for the linear accelerators and MLCs. Some of the QA issues are related to the specific IMRT delivery method, and the specific treatment planning system. This review course will discuss (1) the characteristics of three major MLC collimators and the specific QA related to the unique MLC design; (2) additional QA for linear accelerators pertinent to the small MU and small field sizes used in IMRT; (3) tools often used to perform these QA tasks; (4) specific QA issues for different IMRT delivery methods, step and shoot vs sliding window.

Educational Objectives:
1. Understand the characteristics of three major MLC systems.
2. Understand different IMRT delivery methods and their specific QA issues.
3. Understand effect of QA on the IMRT delivery accuracy.

Therapy Continuing Education Course Room 230A
CE: A Medical Physicist's Guide to the IEC

TH-B-230A-01
A Medical Physicist's Guide to The International Electrotechnical Commission (IEC)
G Ibbott*, UT M.D. Anderson Cancer Center, Houston, TX

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardization and as references when drafting international tenders and contracts.

Through its members, the National Committees of participating countries, the IEC promotes international cooperation on all questions of electrotechnical standardization. The IEC embraces all electrotechnologies including radiology and radiation oncology, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety and the environment.

IEC standards are developed by its technical committees, of which TC 62 addresses electrical equipment in medical practice. Within TC 62, Subcommittee 62C deals with equipment for radiation therapy, nuclear medicine and dosimetry. And within the subcommittee, Working Groups are responsible for writing IEC standards and technical reports. These standards dictate how electrical equipment shall be built, primarily from the standpoint of safety, although some technical reports address performance issues. For example, recent standards, or amendments to existing standards, have defined the coordinate systems to be used by radiotherapy equipment (forcing all manufacturers to change in one way or another to comply); specified the allowable leakage through multileaf collimators; and strengthened requirements for treatment planning systems. At this writing, WG-1 is revising the performance standard for linear accelerators.

Membership on a Working Group is through a National Committee. The US National Committee is responsible for coordinating distribution of IEC drafts for review, collecting and submitting comments and votes, and recommending participation at meetings. IEC standards are too complex and carry too much significance for one person to manage, so the US has established a technical advisory group (TAG) to support the US representatives to the working groups. The role of the US TAG is to contribute to the preparation of these documents and ultimately advise the USNC how to vote on the final approval of the documents.

The US TAG consists of nine members supported by AAPM, ASTRO and ACR, but includes another 8 members representing industry and the regulators. TAG meetings are generally scheduled shortly before meetings of WG-1, to prepare the US position on documents to be discussed. On occasion, conference calls are used, but generally TAG meetings are face-to-face, to facilitate discussion.

To summarize: This is a valuable activity that is critical to assure that radiation therapy equipment design properly balances the safety of patients, staff and the public; the desires for new capabilities; and practical and efficient use. Maintaining a medical physics presence on IEC committees and working groups is essential to ensure that economic issues and regulatory pressures do not dictate equipment design.

Educational Objectives:
1. Become familiar with the structure of the IEC and the working groups that develop standards.

2. Appreciate the significance of IEC standards and their influence on the design of radiation oncology equipment.
3. Learn about several specific IEC standards and how they have affected the design of equipment in use today.

Therapy Scientific Session Room 224 C
Brachytherapy III

TH-B-224C-01

Permanent Prostate Brachytherapy Using Plastic Palladium-103 Seeds

Q Chen*, H Blair, Celveland Clinic Foundation, Cleveland, OH

Purpose: A new model of palladium-103 (Pd-103) seeds with plastic encapsulation (OptiSeed^{103} Model 1032P, International Brachytherapy, Norcross, Georgia) is commercially available. The abstract reports the investigation of using the plastic Pd-103 seeds in prostate brachytherapy. **Method and Materials:** The RTOG criteria were adopted in patient selection. A real-time transrectal-ultrasound (TRUS) guided transperineal implant technique was employed. A Foley catheter was used to localize the urethra. The seed placement followed a modified uniform loading protocol. At the completion of an implant, TRUS images were recorded. Post CT dosimetry was accomplished in the patient's 30-day follow-up visit and a seed migration survey was also performed. **Results:** Three prostate cancer patients underwent the Pd-103 seed implantation. 386 loose seeds with total activity of 656.1 U were implanted. The patients tolerated the procedure. No abnormal symptoms have been reported in the first half-year follow-up, except the detection of 3 migrated seeds to the lungs in a patient. The seed appearances in the pelvic radiographs and CT images were similar to that of the metallic seeds. A significant seed enhancement was observed in the post-implant TRUS images. Phantom studies showed similar results. A post plan for each patient was generated on the post-implant TRUS images where 97% of the seeds were identified with confidence. The patterns of the seed distribution in the TRUS and CT images were similar although the GTVs were different due to implant edema. **Conclusion:** Regarding the dosimetry and implant process, there are no differences between the plastic and metallic seeds. A superior property of the plastic seeds is its appearance in TRUS images. The seed distribution can be immediately displayed in the TRUS images at the completion of an implant. Cold spots can be identified in real time and additional seeds may be added so as to improve the implant quality.

TH-B-224C-02

Performance Evaluation and Optimization of a Novel Brachytherapy Robot

M Meltsner*, N Ferrier, B Thomadsen, University of Wisconsin, Madison, WI

Purpose: To evaluate and optimize the performance of a prototype robotic manipulator designed for prostate seed implantations in a gel phantom. Methods and Materials: The prototype design is a custom-built six degree-of-freedom robot engineered for highly accurate prostate seed implantations. The robot allows for a fully automatic insertion or a manually assisted implantation using the device as a guide. The accuracy was determined using a gel phantom with a holed-template placed at 10 cm depth. Insertion speed and rotation were varied, and the distance from the target hole was measured. The effect on the gel due to needle rotation was observed for increased damage. The experiment included both manual and automatic insertions using 30 cm, 17-gauge, beveled-tip prostate brachytherapy needles. **Results:** The optimal techniques were automatic insertions with a rotation speed of 10 rev/s or 1 rev/s. This provided a "hit" of the target 67% of the insertions with maximum displacement in the "non-hit" insertions of 2.1 mm. The least accurate technique utilized a non-rotated needle, which deflects towards its beveled-tip as inserted. The total displacement from the target with this technique reached distances of greater than 8 mm for a 10 cm depth insertion with an average of 6.9 ± 0.8 mm. **Conclusion:** Preliminary results yielded an optimization of insertion parameters which increased the accuracy from near 1 cm to sub-millimeter displacements. The robot was determined to have a high accuracy in tip placement within the gel. Rotation of the needle can dramatically increase the accuracy of the tip's final position. Rotating the needle at 1 rev/s yielded an accurate implant with minimal increase in gel damage. The robot used in conjunction with an optimized needle insertion technique benefits the patient with increased accuracy, leading to a more successful outcome and reduced complications.

TH-B-224C-03

Robotically Assisted Needle Placement for Prostate Brachytherapy

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Purpose: To present preliminary results for a robotically-assisted prostate brachytherapy treatment system. **Method and Materials:** A 4 degree-of-freedom (DOF) robotic device was developed to replace the ultrasound template in a commercially available prostate brachytherapy treatment system (Interplant, Computerized Medical Systems, St. Louis, MO). The robot mounts to the existing template mounting points on the ultrasound stepper, and is capable of positioning the needles at arbitrary positions and orientations. The robot is spatially co-registered to the Interplant treatment planning software through a calibration procedure. We performed a seed-implantation experiment on a prostate training phantom in which the needles were positioned by the robot. The needles were preloaded with one seed, then inserted manually by the operator under transrectal ultrasound (TRUS) guidance. In this experiment, ten seeds were implanted, and their implanted positions were reconstructed using data from a post-implant CT of the phantom and the Interplant post-implant analysis software (iPAS). **Results:** Using the results from the iPAS software, we measured both the relative error of each seed (with respect to the other seeds), and the absolute error of each seed with respect to the treatment plan. The relative root-mean-square (RMS) transverse error was 0.8 mm (worst case 2.1 mm, 70% under 0.7mm), and the relative RMS sagittal error was 2.5 mm (worst case 4mm, 60% under 2.5 mm). The absolute transverse RMS error was 2.4 mm (worst case 4.3 mm, 50% under 2.4 mm), and the absolute sagittal RMS error was 2.5 mm (worst case 4.5 mm, 80% under 2.5 mm). However, the absolute transverse errors were characterized by an offset in each direction, most likely resulting from errors in the measurement of the robot position relative to the phantom. **Conclusion:** Our system for robotically-assisted prostate brachytherapy shows potential for improved needle placement, repeatability, and accuracy.

TH-B-224C-04

Feasibility of Calibrating Elongated Brachytherapy Sources Using a Well Type Ionization Chamber

A Meigooni*, S Awan, k dou, Univ Kentucky Medical Center, Lexington, KY, University of Kentucky, Lexington, KY, University of Kentucky, Lexington, Kentucky

Purpose: TG-43 recommended parameters of a brachytherapy source require calibration of the source using the WAFAC system by the NIST. However, the presently available NIST standard system is limited for calibration of sources with active lengths ≤1 cm. A new procedure has been introduced for calibration of elongated brachytherapy sources (i.e. active lengths > 1 cm) as an interim solution to the calibration standards by the NIST. This procedure is based on commercially available well type ionization chambers. **Materials and Methods:** The variation of the source calibrator response as a function of the source position along the longitudinal axis of the chamber was measured to determine the relative correction factor (RCF). Then the NIST calibrated source was used to calibrate the response of the source calibrator. A train of the 1 cm source segments were used to create elongated sources with different active-lengths ranging from 1 cm to 7 cm. The measured air kerma strength were compared with the total source strengths calculated as the sum of the individual 1 cm source segments utilized to compose the source. **Results:** The results of these investigation have indicated that the response of the Capintec CRC was nearly constant (within 0.5 %) for distances ranging from 4.9 cm to 14.9 cm from the bottom of the chamber. With this information and a calibration factor of 4.881 Reading/U, air kerma strengths of RadioCoil™ Pd-103 sources with active length of 1 to 7 cm were measured. The results of these measurements were found to be within ± 0.4% of the values calculated by addition of the 1cm source segments used in creating the sources. **Conclusion:** A well type chamber with the calibration for the 1 cm long RadioCoil™ ^{103}Pd source segment can be utilized for calibrating of an elongated source with different active lengths sources.

Educational Symposium Room 330 D
Symposium on the Challenges, Opportunities, and Resources for the Future of Medical Physics Education

TH-C-330D-01
Introduction and Overview
P Sprawls*, Emory Univ School of Medicine, Montreat, NC

Medical physics education, especially for radiologists and medical physicists, is faced with several significant challenges because of a variety of conditions including the rapid changes in diagnostic and therapy technology and methods that must be addressed, prevailing attitudes on physics education within the clinical practice, and the need for qualified faculty and educational resources.

Effective and efficient medical physics education for the future will result from a general re-engineering and adopting revised models of the educational process to clearly define the needs and desired outcomes of educational activities and then develop a variety of methods and resources that will use state-of-the-art technology to enhance the performance of both the learners and learning facilitators/teachers.

This symposium provides a forum for exploring several current activities and initiatives that are significant to the future of medical physics education.

TH-C-330D-02
The Forum On Medical Physics Education: Outcomes and Directions for the Future
W Hendee*[1], H Mower[2], (1) Medical College of Wisconsin, Milwaukee, WI, (2) Lahey Clinic, Burlington, MA

Medical physics education leaves much to be desired. The depth and breadth of education of radiologists in the fundamental physics of their profession is simply inadequate when contrasted with the complexity of imaging technologies and the sophistication of imaging procedures. The use of image guidance and complex treatment delivery systems and algorithms in radiation oncology calls for a substantial increase in the level of understanding of physics and its applications by radiation oncologists. These needs provide excellent opportunities for medical physicists to improve their contributions to the education of their physician colleagues, and through this process improve the care of patients in radiology and radiation oncology. Before these opportunities can be exploited to their fullest, however, the education of medical physicists in the clinical applications of radiology and radiation oncology must be improved. In January, 20-22, 2006 a forum on the physics education of radiologists, radiation oncologists and medical physicists was held in Atlanta. The meeting was hosted by the American Association of Physicists in Medicine, and representatives of 30 radiology, radiation oncology and medical physics organizations attended the meeting. Participants examined the guidelines for education of specialists in all 3 fields, together with expectations of accrediting agencies (eg CAMPEP and ACGME-RRC) and certification organizations (ABR, ABMP), and developed a number of consensus recommendations on how the various organizations could communicate and work more closely together to improve the physics education of individuals in all 3 specialties. These recommendations will be presented for discussion in this forum, with the purpose of seeking feedback on the recommendations and encouraging implementation of the recommendations in the participants' institutions.

TH-C-330D-03
Web-Based Education: Current and Future Resources and Applications
G Frey*, Medical Univ of South Carolina, Charleston, SC

The course will present a review of web based educational materials for medical physicists. This material can be divided into a number of broad categories. These include: 1) Materials that are available to the physicist that can be used as part of a program for teaching radiology residents, radiation oncology residents, medical physics students and technologists; 2) Materials that can assist the physicists in self-directed professional development and maintenance of certification; 3) Materials that are designed for use by students and physicists in developing areas; and 4) Materials that are designed to help physicists locate and use materials in the other categories.

This lecture will review materials in the various categories to assist medical physicists with locating and using appropriate materials.

Educational Objectives:
1. The participant will become aware of educational materials that are available on the web
2. The participant will be able to locate appropriate materials for web based SDED
3. The participant will be aware of the many different professional areas in which web based materials exist

Imaging Scientific Session Room 330 A
Imaging Performance Measurement and Modeling

TH-C-330A-01
Data Cube Based Tumor Respiratory Motion Characterization
Y Wu*, J Klinginsmith[1], H Wu[2], (1)Indiana University, Bloomington, IN, (2) Indiana University Purdue University Indianapolis, Indianapolis, IN

Purpose: Adequate understanding and precise characteristics of tumor motion is essential for accurate radiation dose delivery in real-time image-guided radiation treatment. We propose a data cube based approach for representing, analyzing and characterizing tumor motion information at various concept levels. More precise patient clustering and characterization can be achieved by combining the tumor motion information and the patient biomedical information. **Method and Materials:** Based on a finite state model, a breathing cycle of tumor motion is represented by three line-segments: exhale (EX), end-of-exhale (EOE) and inhale (IN). A *data cube* is constructed to provide the means of multi-dimensional data analysis that computes summary information based on arbitrary combination of dimensions. Data navigation methods – *roll-up, drill-down, slice-and-dice* – are applied to assist in interactively selecting points of interest and navigating among the concept hierarchy. Patient clusters and motion patterns are detected with the assistance of the visualization tools and advanced data mining techniques, such as K-means clustering algorithm. In addition, we incorporate the patient biomedical information in this process to obtain more precise patient motion classification and characterization. **Results:** Experiments have been performed on real patient data. Using our approach, summary information is generated automatically and visually displayed. Patient clustering can be easily detected manually or by clustering algorithms. Interesting motion patterns have been discovered from out preliminary results. More precise patient clustering and motion characterization are accomplished when the approach is used on the combination of motion information and patient biomedical information. **Conclusion:** The data cube based tumor motion characterization approach not only eliminates all the manual processing on patient motion characterization, but also provides the facility to refine the patient clustering and detect interesting patterns, which will provide valuable input for better understanding of tumor motion and for effective real-time image guided radiation treatment.

TH-C-330A-02
Does Image Quality Impact Mammographic Accuracy?
R.S. Saunders, Jr.* and E. Samei; Duke Advanced Imaging Laboratories, Department of Radiology, Duke University Medical Center, Durham, NC and Department of Physics, Duke University, Durham, NC

Purpose: To assess the impact of resolution and noise on observer performance in detecting and classifying breast masses and microcalcifications in x-ray mammography. **Method and Materials:** Simulated breast masses and microcalcifications were inserted into normal digital mammograms. A routine modified the images to simulate the effects of reduced dose. Images were viewed on three medical-grade displays: an LCD, a CRT with normal resolution, and a CRT with degraded resolution. Five experienced breast imaging radiologists scored the lesions in the image set using a custom graphic user interface based on

a categorical rating paradigm. The data were analyzed to find overall accuracy and accuracy for four specific diagnostic tasks (detection of benign masses, malignant masses, and microcalcifications, and discrimination between benign and malignant masses). **Results:** When using different displays but keeping noise constant at full dose, radiologists had similar overall accuracy (LCD: 0.83 ± 0.01, CRT_{Normal}: 0.82 ± 0.01, $CRT_{Degraded}$: 0.84 ± 0.01). The radiologists also had similar accuracy for each of the four clinical tasks on the three displays. Overall, no statistically significant difference in clinical accuracy was observed between the three displays ($p > 0.05$). When varying dose levels while only using the LCD display, the radiologist performance dropped somewhat (full dose: 0.83 ± 0.01, half dose: 0.77 ± 0.02, quarter dose: 0.61 ± 0.02). Noise had the greatest impact on the detection of microcalcifications and discrimination between benign and malignant masses. **Conclusions:** This work suggests that the choice of medical display has a small impact on clinical accuracy in digital mammography. The small drops in clinical performance with increased noise suggests that dose may be somewhat decreased with limited impact on clinical utility. The categorical rating paradigm should be considered for future investigations as it allows for greater image throughput while closely modeling the clinical paradigm.

TH-C-330A-03

Does Display Bit-Depth Influence Observer Performance?

E Krupinski*, H Roehrig, J Fan, Univ Arizona, Tucson, AZ, Univ AZ Health Science Center, Tucson, AZ, University of Arizona, Tucson, AZ

Purpose: The display a radiologist reads images from represents a crucial link in the information chain. There has been much debate recently on what bit-depth is necessary for optimal reading. Greater bit depth permits more gray levels to be displayed initially, possibly obviating the need for the observer to window/level the image during viewing. This project compared an 8-bit with 11-bit LCD display in terms of observer performance. **Method and Materials:** Two Totoku LCD displays (3 Mpixel, grayscale) were used that were identical in every way except for the bit-depth. One was 8-bit and the other 11-bit. Max luminance was set to 500 cd/m2 and min luminance was set to 0.6 cd/m2. The displays were DICOM calibrated and room lights were set to the average display luminance with an image displayed. A set of 100 DR chest images, half with nodules and half without, were shown to 6 radiologists in a counter-balanced Receiver Operating Characteristic study. They reported whether a nodule was absent or present and rated heir confidence. **Results:** Performance (ROC Az values) was essentially equivalent for the two bit-depth displays. There were no significant differences in viewing time or how often the readers used the window/level functions. **Conclusion:** For chest images with nodules it appears that having greater than 8-bit depth does not significantly enhance observer performance. It is not clear whether the results would be the same with different types of images or lesions. **Conflict of Interest:** Totoku provided the displays, software and funds to reimburse the radiologist observers.

TH-C-330A-04

Novel Learning-Based Approach to Optimal EPID Image Deblurring and Enhancement

P Roessler*[1], J Maltz[1] , O Somphone[1], E Blanz[2], B Gangadharan[1], F Ghelmansarai[1], O Morin[3], J Pouliot[3], A Bani-Hashemi[1], (1) Siemens Medical Solutions USA, Inc., Concord, CA, (2) Siemens Medical Solutions, USA, Inc., Malvern, PA, (3) UC San Francisco, San Francisco, CA

Purpose: Finite focal spot size in X-ray imaging equipment has a blurring effect on acquired images. For practical reasons, it is neither possible nor desirable to reduce the spot size of medical linacs below a certain diameter. This affects task performance in IGRT, where the blurring of the edges of structures reduces positioning accuracy. Since the focal spot size and shape of linacs vary, the filter must be customized to a particular linac. We have developed an algorithm that learns to deblur portal images by comparing actual images to their Monte Carlo (MC) generated ideal counterparts. **Method and Materials:** A training object containing sharp edges of all orientations is imaged to capture the blurring and noise characteristics of the system. MC simulations in which a point source irradiates a digital version of the training object are used to generate ideal images. These are used as training data to optimize the convolution kernel that effects deblurring. Owing to the nature of the training data, the kernel will deblur the image as well as enhance edges. We assume since the object is 1m from the source, blurring is uniform for all transverse object planes. **Results:** Large samples of phantom and patient images were used to evaluate filter performance. A marked improvement in image quality is apparent. Evaluation of spatial resolution (MTF) and contrast-to-noise ratio (CNR) reveals a dramatic improvement in MTF but reduction in CNR. However, since the CNR remains above 70 at doses of 1MU, the increase in noise will not effect IGRT task performance. **Conclusion:** This work indicates the utility of this novel image enhancement technique in clinical images. In particular, visibility of small objects in images, such as prostate seeds, is remarkably enhanced.

Conflict of Interest: Sponsored by Siemens.

TH-C-330A-05

Analysis of the Point Spread Function of Isocentric Digital Tomosynthesis (DTS)

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Purpose: This project presents an analysis of the point spread function (PSF) of isocentric digital tomosynthesis (DTS). DTS is a limited angle 3-dimensional reconstruction from cone beam projections, with high resolution for excellent imaging of both bony anatomy and soft tissue. Its major application is on-board imaging. The scans can be acquired during a single breath hold, thus eliminating respiratory motion artifacts without gating techniques. **Method and Materials:** The geometry of a linear accelerator (Clinac 21EX from Varian) equipped with a kV on-board imager and CBCT capability was used. We simulated projection data sets of a single point source (PS) for different total scan angles from 26^o to 58^o. The PS was located along the horizontal axis through the isocenter from the kV x-ray source to the detector (z-axis). DTS reconstructions were generated from the simulated projections, using a standard Feldkamp technique. The full width at half maximum (FWHM) of the resulting PSF was computed along the z-direction in stacks of DTS slices. **Results:** The PSF shows a bow-tie shape in the z-direction. The spread of the blurring function increases for larger scan angles. Furthermore, the FWHM decreases as both distance from the detector and the scan angle increase. FWHM values ranged from ~2.5mm to ~5mm near the kV source, and from ~5mm to ~11mm near the detector, as the scan angle was varied. For a typical 44^o scan, the FWHM varied from ~3mm when the PS was moved 20cm towards the source away from the isocenter, to ~6mm when was moved 24cm towards the detector. **Conclusion:** The blurring effect of isocentric DTS is dependent on the total scan angle and the point of interest. These characteristics will provide guidance to imaging techniques using DTS for clinical applications.

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TH-C-330A-06

Effects of KVp Setting and Radiation Dose On Calcification Visibility in Cone Beam CT

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Purpose: To investigate how the kVp setting and radiation dose affects the detection of microcalcifications in cone beam CT (CBCT). **Materials and Methods:** Calcium carbonate grains, ranging from 200-212 to 355-425 micron, were used to simulate microcalcifications. The simulated microcalcifications from the same size were arranged to form a 5×5 microcalcification cluster. Each cluster was embedded between two slices of a stacked lunch meat and positioned at the center of each slice of the lunch meat. The lunch meat was then imaged with an experimental CBCT system, which employs a 30 × 40 cm2 a-Si/CsI based flat panel detector with a pixel size of 194 microns. 300 projection images over 360 degrees were acquired in the non-binning mode at two kVp setting (60 and 80 kVp) and various doses (4.2, 6, 12, 18, and 24 mGy). The projection images were reconstructed with the Feldkamp algorithm. After that, 767×767×9 volume data were extracted from the CBCT reconstructed images for each MC size group and each dose level as well as each kVp. The images were sequentially displayed on a review workstation with a 1600×1200 CRT monitor and reviewed by six readers independently. The order of the images was randomized for each reader. The readers were asked to count the number of visible microcalcifications. The ratios of the visible microcalcifications were averaged over all readers. Student t-test was used

to compute the p values. **Result:** For 80 kVp, the images acquired with 4.2 mGy performed similarly to those acquired with 6 mGy ($p > 0.05$) for each MC size. Additionally, the images acquired with 18 mGy performed similarly to those with 24 mGy ($p > 0.05$) for most MC sizes.

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Noise and Nodule Detectability in Simulated Cone Beam CT Imaging

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Purpose: To evaluate and quantify the impact of various types of noise (quantum noise, photon scatter, flat panel detector blurring, and system noise) on the nodule detectability in simulated cone beam CT (CBCT) images by conducting the eight-alternative forced choice (8-AFC) observer performance experiment. **Method and Materials:** We used Radon transform formalism to mathematically model a 3D chest phantom with spherical nodules of various sizes. Quantum noise, photon scatter, detector blurring, and system noise were then simulated and added to the projection images individually. The projection images were reconstructed by using the Feldkamp algorithm and the final images were then used for the observer performance study. Other impact factors for the image quality (e.g., contrast variation, x-ray dose, nodule size, number of projection images, cone beam angle etc.) were also incorporated into the reading study. Detection curves were then determined statistically from the 8-AFC experimental data by using a maximum-likelihood method. Nodule detectability was then quantified directly from the reading performance participated by 6 observers in the 8-AFC tests. **Results:** Our preliminary data indicated that at the high x-ray dose level, photon scatter had the highest impact on the simulated CBCT images; while at the low dose level, system noise had the biggest impact. At all tested dose levels, detector blurring had the lowest impact on the detectability. In consistent with the previous theoretical study, the nodule detectability can be improved by increasing the number of projection images. **Conclusion:** Our work indicated that using photon scatter correction techniques and reducing the system noise had the biggest potential to improve the CBCT image quality. We are currently investigating the impact of various scatter reduction algorithms and reconstruction methods on the CBCT image quality.

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TH-C-330A-08

Soft-Tissue Detectability Limits in Cone-Beam CT: 2AFC Tests of Human Observer Performance in Relation to Contrast, Spatial Resolution, and the 3D Noise-Power Spectrum

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Purpose: To quantify the contrast-detail detectability limits of soft-tissue structures in cone-beam CT (CBCT) and to investigate the influence of the plane of visualization (axial/sagittal) and level of prior knowledge on observer performance. **Method and Materials:** Custom-built cylindrical phantoms containing spherical lesions of varying size and contrast were imaged on a CBCT bench across a broad range of dose. Two-alternative forced choice (2AFC) tests were conducted under controlled conditions using 7 observers (physicists and radiation therapists). For each 2AFC test, the proportion of correct responses, Pcorr, was analyzed as a function of lesion size (1.6 – 12.7mm) and contrast (20 – 165HU), dose (2.1 – 6.4mGy), plane of visualization (axial/sagittal), apodization filter (smooth Hanning to sharp Ram-Lak), and degree of prior knowledge provided to the observer (ranging from Signal-Known-Exactly (SKE) to Signal-Unknown (SUK)). **Results:** 2AFC analysis provided valuable quantitation of contrast-detail detectability limits. For example, the lowest contrast lesion (20 HU) was detected at Pcorr>70% for diameters down to ~6mm at doses >2mGy, but smaller 20 HU lesions (<3.2mm) were barely detectable (Pcorr<60%) at any dose. Detectability was significantly improved in axial versus sagittal planes, and the effect was amplified by sharper apodization filters in a manner consistent with 3D noise-power spectrum asymmetry. Prior knowledge had a marked influence on detectability – e.g., a ~6mm (20 HU) sphere was detected at Pcorr~70-85% for SKE conditions, compared to Pcorr~55-65% under SUK conditions across the same range of dose.**Conclusion:** Comprehensive human observer tests provide valuable quantitation of soft-tissue detectability limits in CBCT and help to define low-dose techniques for specific imaging tasks. Two factors in particular – plane of visualization and prior knowledge – hold significant practical implications: axial planes typically offer improved detectability, and performance is maintained at significantly lower dose under SKE conditions (e.g., lesion-known image guidance) than in SUK conditions (lesion-unknown diagnostic imaging).

TH-C-330A-09

Cascaded Systems Analysis of Noise Reduction Algorithms for Dual-Energy Imaging

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Purpose: While dual-energy (DE) imaging provides increased nodule conspicuity in soft-tissue images and greater calcification visualization in bone-only images, DE image decomposition amplifies noise present in the projection data. This paper extends task-based cascaded systems analysis (CSA) to include a variety of DE noise reduction algorithms, offering a general analytical approach to optimizing DE imaging performance. **Method and Materials:** Two noise reduction algorithms [simple-smoothing of the high-energy image (SSH) and anti-correlated noise reduction (ACNR)] were incorporated into CSA models for DE imaging to describe the DE modulation transfer function (MTF^{DE}), noise-power spectrum (NPS^{DE}), and noise equivalent quanta (NEQ^{DE}). The MTF^{DE} and NPS^{DE} were measured using standard edge-spread function and flood-field techniques adapted to DE imaging (with noise-reduction processing) and compared to theoretical results. The MTF^{DE} and NPS^{DE} were combined to yield the NEQ^{DE} and integrated with a spatial-frequency-dependent task function to provide a detectability index for evaluation of imaging performance using standard, SSH, and ACNR image decompositions. **Results:** The MTF^{DE} and NPS^{DE} calculated using CSA agreed well with measurements. Detectability index provided an objective performance metric for identifying superior noise reduction algorithms under conditions of varying kVp, dose, and imaging task. For example, the DE detectability index for a delta-function detection task in the soft-tissue image was by far greatest for the ACNR algorithm, whereas SSH performed best for the bone-only image. A gaussian detection task, on the other hand, indicated superior performance for the ACNR algorithm for both soft-tissue and bone-only images. **Conclusions:** Extension of CSA to include the influence of DE noise-reduction algorithms such as SSH and ACNR offers a powerful guide to system optimization. The general, analytical approach provides an objective means of selecting superior noise-reduction algorithms and "tuning" the parameters therein in a manner that weighs spatial resolution and noise in relation to the imaging task.

Joint Imaging/Therapy Scientific Session — Valencia B

Tomographic Imaging for Therapy Localization

TH-C-ValB-01

Prostate Contouring Uncertainty in Mega-Voltage Computed Tomography (MVCT) Images Acquired with a Helical Tomotherapy Unit During Image-Guided Radiation Therapy (IGRT)

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Purpose: To evaluate the image guidance capabilities of helical tomotherapy-based MVCT, this work compares the inter- and intra-observer contouring uncertainty in KVCT used for radiotherapy planning with MVCT acquired with a tomotherapy unit. Methods and Materials: Five prostate cancer patients who underwent tomotherapy treatment (with

daily MVCT) at our institution were selected. One planning KVCT and one randomly selected MVCT from each patient were used. Slice spacings for KVCT and MVCT were 3 mm and 6 mm, respectively. Retrograde urethrography was performed on the KVCT studies only. For inter-observer study, seven observers contoured the prostate on the 10 CT studies. For intra-observer study, the same seven observers repeat-contoured one patient's KVCT and MVCT studies. Quantitative analysis of contour variations was performed using volumes and radial distances. F-test was performed to detect statistically significant differences between KVCT and MVCT. **Results:** The inter- and intra-observer contouring variability was larger in MVCT than KVCT. The largest variability was mainly found in the prostate apex and base regions. Up to 1 cm (SD) was found in MVCT. In the prostate apex region, interestingly, large but similar variability between KVCT and MVCT was observed. This suggest that the use of urethrography during KVCT simulation was not very helpful. For F-test, generally, the regions with significant differences were patient-dependent and uniformly distributed in all directions. In terms of prostate volume, observers consistenly contoured larger prostate in MVCT (by 10 %). This reflects the poorer soft-tissue contrast in MVCT than KVCT since observers tend to over-estimate or over-draw target volumes under less visible conditions. **Conclusions:** Based on our data, the application of MVCT for estimating daily organ motion and deformation during image-guided radiotherapy (IGRT) is somewhat discouraging. Optimization of slice thickness and dose utilization may result in better imaging performance for prostate delineation and adaptive tomotherapy.

TH-C-ValB-02

Clinical Implementation of Cone-Beam CT for Image-Guided Radiation Therapy

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Purpose: A linear accelerator equipped with cone-beam CT (CBCT) was commissioned for image-guided radiation therapy in an IMPAC's Multi-Access environment. The purpose of this work is to report our experience of clinical implementation of CBCT in a multi-vendor environment. **Method and Materials:** The mechanical accuracy of the system was tested using a stereotactic method to verify the imaging isocenter congruent with the therapy isocenter of the accelerator (Trilogy, Varian). Image qualities, including the high contrast resolution (HCR) and low contrast resolution (LCR), were evaluated and compared with the conventional CT (Catphan 600). Imaging doses were measured using TLDs in several anthropomorphic phantoms for the intended treatment sites (head, chest, and pelvis). There are connectivity issues with current vendor provided software, the clinical implementation of CBCT relies on in-house CT-assisted targeting (CAT) software, which is used for aligning CBCT images to the planning CT to determine daily setup shifts. The alignment uncertainties and its dependence on imaging dose were verified in phantom with various known couch shifts. **Results:** The imaging isocenter was found to within 1 mm of the therapy isocenter. The CBCT HCR is similar to the conventional CT, approximately 6~7 lp/cm, while the LCR is inferior. The CBCT LCR with bow-tie appears better than without. With bow-tie, the average imaging doses using built-in protocols were 7.1, 6.7 and 4.3 cGy in head, chest, and pelvis phantoms, respectively; without bow-tie, doses were 5.4 and 2.4 cGy for head and pelvic phantoms. Workflow was implemented to use the in-house CAT software with vendor supplied CBCT acquisition software. The CAT software can predict overall sub-millimeter accuracy in a phantom experiment with many known couch shifts. **Conclusion:** We have successfully implemented CBCT for clinical use. Major challenges included various component testing, connectivity, and in-house software implementations.

TH-C-ValB-03

Quality Assurance Procedure for a KV Cone-Beam Device

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Purpose: To establish a quality assurance procedure for kV cone-beam (CB) devices, and use the procedure to assess the accuracy and precision of a particular CB unit. **Introduction:** The introduction of the Elekta CB system has created a need for a quality assurance (QA) procedure to test the system's reliability and accuracy and it's alignment with the MV treatment beam isocenter. **Materials and Methods:** An acrylic phantom with dimensions of 18x19x18 cm^3 was used for this work. The phantom included a central slab made of polystyrene that contained two drill holes. One was drilled to the center of the cube, and the other was off to one side and established phantom orientation during scanning. The holes were left open during CT and CB imaging to minimize artifacts. The phantom was first positioned with the center hole at the accelerator mechanical isocenter. Repeated cone-beam datasets were acquired to determine the system's ability to detect and correct for known table shifts. Finally, the phantom was positioned with CB guidance and the beebee was placed in the center hole. The Winston-Lutz (WL) test in the phantom was preformed using the electronic portal imager (EPID). The differences between known and CB determined shifts and the WL test analysis were tabulated. **Results: and Conclusion:** The results showed that the cone-beam system was capable of determining the shifts applied to the QA phantom to within 0.5 $\pm$ 0.4 mm with the largest difference between the known and calculated shift of 1.9 mm. The mean agreement between the kV and MV isocenters was 0.5 mm $\pm$ 0.4 mm with the largest deviation of 1.3 mm. This QA study supports a conclusion that the Elekta CB system can be reliably used for positioning of patients with the accuracy in a 1 to 2 mm range.

TH-C-ValB-04

Evaluation of the Quality of 3D-3D Mutual Information (MI) Shared Between Reference and On-Board DTS Images

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Purpose: Digital tomosynthesis (DTS) is a fast, low-dose method for reconstructing 3-D slices from 2-D cone-beam x-ray projection data acquired with limited source angulation (e.g., 40^o). We previously developed a method for reconstructing reference DTS (RDTS) images from a planning CT volume, for registration with on-board DTS image data. This study examines 3D-3D mutual information (MI) shared between RDTS and DTS volumes of an anthropomorphic chest phantom. **Method and Materials:** Planning CT and on-board CBCT volumes of an anthropomorphic chest phantom were aligned by a point-registration of 6 metal fiducials. Misregistration (+/- 5mm and +/- 5^o) was simulated along each of the six possible translational and rotational dimensions of the planning CT volume. For scan angles spanning 10^o-60^o, RDTS images were reconstructed from each of the misregistered CT volumes and DTS image sets were computed from actual on-board projections. 3D-3D MI between each RDTS and DTS volume was computed for a 4cm x 10cm x 7.5cm central region of interest containing the spine. MI was plotted as a function of each of the six possible translations and rotations, for each DTS scan angle. **Results:** For all scan angles greater than 10^o, residual error in the location of global MI maxima was less than 1.0 mm, and 0.5^o. MI resolution to shifts in the depth dimension (normal to individual DTS planes) improved noticeably with increasing scan angle. MI sensitivity to all other shifts and rotations showed only minor improvement with increasing scan angle. **Conclusion:** MI between planning CT-generated RDTS and actual on-board DTS image data is sufficient to be used for rigid-body registration purposes. The addition of an orthogonal DTS acquisition (i.e., acquiring sagittal along with coronal DTS) is probably unnecessary for rigid-body DTS registration. **Conflict of Interest:** This research was supported in part by a grant from Varian Medical Systems.

TH-C-ValB-05

Rapid Low-Dose 3D Image-Guided Treatment Verification of Sites Prone to Respiratory Motion Using Breath-Hold On-Board Digital Tomosynthesis (DTS)

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Purpose: This study examines the potential use of on-board digital tomosynthesis (DTS) for image-guided treatment verification of sites prone to respiratory motion. DTS is a fast, low-dose method for reconstructing 3-D images from 2-D projection data, acquired with a limited scan angle. In the treatment room, a 45^o DTS scan can be acquired in less than 10 seconds, making rapid breath-hold DTS a simple method for acquiring 3-D treatment verification images, devoid of respiratory motion. **Method and Materials:** On-board DTS images of ten human liver, pancreas, and lung subjects were reconstructed from kV CBCT projection data, acquired on a Varian 21EX Clinac equipped with an on-board imager (OBI), either during a breath-hold or while subjects were freely breathing.

Corresponding reference DTS (RDTS) images were reconstructed from breath-hold planning CT data. Soft-tissue visibility was compared between breath-hold DTS and free-breathing DTS and CBCT, to assess the potential efficacy of the breath-hold DTS strategy for 4-D image-guided treatment verification. **Results:** Breath-hold DTS markedly improved the rendering of soft-tissue abdominal and thoracic anatomy, compared with free-breathing DTS or CBCT. Organ structures were clearly defined, and even low-contrast target malignancies were often visible in breath-hold DTS reconstructions. Free-breathing DTS and CBCT reconstructions, on the other hand, often exhibited artificially enlarged target volumes and poor visibility of soft-tissue anatomy, due to motion averaging effects. **Conclusion:** Rapid breath-hold DTS enhances the visibility of bony and soft-tissue anatomy in sites prone to respiratory motion, facilitating daily localization of soft-tissue targets. Breath-hold DTS localization is superior to free-breathing on-board CBCT for thoracic and abdominal image-guidance. **Conflict of Interest:** This research was supported in part by a grant from Varian Medical Systems.

TH-C-ValB-06

Thoracic Proton Treatment Planning Strategies Based On the 4D CT Information

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Purpose: Particularly in the case of thoracic radiation therapy, there are substantial inter- and intra-fractional variations in shape, volume and position of treatment targets and the intervening and surrounding normal tissues. The purpose of this work is to develop proton treatment planning strategies for mobile tumors with and without mobile intervening structures based on 4D CT, and to assess the planning strategies using 4D CT data and daily in-room CT information. **Method and Materials:** Five treatment planning strategies were evaluated based on (1) free breathing CT with small smearing, (2) free breathing CT with large smearing, (3) average CT with small smearing, (4) average CT with CT numbers inside the tumor volume replaced by higher CT numbers, and (5) maximum intensity projection CT. For a lung patient with large, 1.6 cm, tumor motion and immobile surrounding tissues, treatment plans were designed using strategies 1, 2 and 4. Each treatment plan was recalculated on five daily CT images using bony structure alignment. For an esophagus patient with 3.5 cm tumor motion and large cardiac, liver and spleen motion, treatment plans were designed using strategies 1, 2, 3 and 5. Each treatment plan was recalculated in all 10 phases of the 4D CT. **Results:** For the lung patient, the tumor coverage evaluated using the five daily CT's is superior when using strategies 2 and 4 as compared to strategy 1. However, the lung sparing is superior using strategy 4 compared to strategy 2. For the esophagus patient, the treatment plans using strategy 2 and 5 covered the targets for each 4D CT phase while the plan using strategy 1 and 3 caused significant under-dosing.**Conclusion:**
With the strategies developed using 4D CT data, good tumor coverage was achieved for the thoracic patients with large tumor and surrounding tissue motion using proton therapy.

TH-C-ValB-07

Enhanced 4D CBCT Imaging for Slow-Rotating On-Board Imager

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Purpose: Four-dimensional (4D) cone-beam CT (CBCT) is currently obtained by respiratory phase binning of the acquired projections followed by independent CBCT reconstruction of the rebinned projections for each phase. Due to the significantly reduced number of projections in a single phase bin, the quality of 4D-CBCT images is severely degraded. In this work, we develop a technique to combine the data from all phases for greatly enhanced 4D CBCT. **Method and Materials:** 4D-CBCT data were acquired with "extremely-slow-gantry-rotation" protocol (1 deg/sec) on a Varian Acuity system. The respiratory phase binning was achieved by automatic texture matching of the CBCT projections, and 4D-CBCT images were subsequently obtained by Feldkamp reconstruction of the phase-binned data. Finally, to enhance the quality, the 4D-CBCT images were superimposed via deformable registration based on maximum mutual information and BSpline model. The method was quantitatively evaluated with numerical and physical phantom experiments. Three clinical cases are also being investigated. **Results:** The numerical and physical phantom studies showed that 4D CBCT resulted in less motion artifacts than 3D CBCT, however, the view-aliasing artifacts are visible in 4D CBCT images due to limited number of projections being used for reconstructing each phase, this led to large fluctuation of the CT numbers in any uniform region and generally reduced contrast-to-noise ratio (CNR). In comparison, the proposed 4D CBCT technique scientifically improved the CT number accuracy, the image uniformity, and the CNRs. **Conclusion:** A novel technique for 4D CBCT imaging with a slow-rotating onboard imager has been developed. It integrates information of different respiratory phases to achieve an enhanced image quality. The improvement on the CT number accuracy is extremely important to image-guide radiation therapy for on-line treatment planning and off-line dose verification.

TH-C-ValB-08

Motion Induced Dosimetric Impacts in Breast 3D Radiation Treatment – a 4D CT Based Study

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Purpose: In radiotherapy treatments of breast patients, respirations may introduce uncertainties in target and heart locations. This study is to investigate the dosimetric impacts of these uncertainties in breast radiation treatments. **Method and Materials:** A 4D CT scan and a conventional helical CT scan set were acquired on each of 7 left breast patients and 5 right breast patients. Using the helical CT scan, a conventional 3D conformal plan, consisting of two tangential beams, was generated per physician's evaluation and decision. The 4D CT scan set was divided into 10 phases over the respiratory cycle. On each phase, treatment target and heart were contoured. Dose distributions were generated using the same beams as in the conventional plan. Software was developed to compute the cumulative dose distribution (4D doses) from all the phases. This 4D CT image based cumulative dose distribution would be closer to that in reality with motions taken into account. Various dosimetric parameters were obtained for treatment target and heart from the conventional plan and from the 4D cumulative dose distributions and compared to deduce the motion induced dosimetric impacts in breast radiation treatments. Studies were performed for both whole and partial breast treatments. **Results:** For whole breast treatment, the motion induced changes in D_{95}, D_{max}, and D_{min} of PTV were $0.88\% \pm 20\%$, $-0.28\% \pm 0.65\%$, and $-10.17\% \pm 47\%$, respectively. For left breast, the motion induced D_{max} change in heart was $22\% \pm 48\%$. For partial breast treatments, the motion induced changes in V_{90} and D_{min} of CTV were $1.6\% \pm 2.7\%$ and $3\% \pm 4\%$, respectively. **Conclusions:**
Breathing motion may cause cold spots in the whole breast treatment, and may compromise treatment quality for some patients. It may also increase heart maximum dose. However, for the partial breast treatment, the motion impact may be insignificant with properly selected margin size.

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TH-C-ValB-09

4D CT Using Retrospective Velocity-Based Amplitude Sorting

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Purpose: To present a technique, velocity-based amplitude sorting (VBAS), which addresses current shortcomings of 4D CT, which is conventionally performed using phase-based retrospective sorting of CT images. The phase of the breathing signal contains little information about the tumor's displacement. When the breathing signal is irregular, blurring artifacts can result. Amplitude-based sorting has the disadvantage that fewer images are acquired when the tumor velocity is large, and therefore may reduce spatial resolution. VBAS analyzes the breathing signal to determine the average tumor velocity, and resizes the amplitude-based sorting bins accordingly. **Method and Materials:** An infrared marker was placed on the patient's chest and tracked by a camera to record the breathing signal. Each CT image was correlated with the breathing signal and sorted into the appropriate bin using one of three methods: (i) phase sorting, (ii) amplitude sorting, and (iii) VBAS. The 8 resulting image sets for each method were interpolated when necessary. Methods (i), (ii), and

(iii) were evaluated by comparing target volumes in reconstructed motion-phantom images. Volumes of 3 patient tumors were also analyzed to determine their reproducibility over every bin for each method. **Results:** The volumes of the targets of the motion phantom were compared to those of a static phantom. The respective errors in the methods were (i) 27%, (ii) 34%, and (iii) 11%. The VBAS technique also resulted in the lowest variability in patient tumor volumes: these were (i) 18%, (ii) 32%, and (iii) 12%, respectively. Qualitatively, the spatial resolution of the VBAS images was greatest. **Conclusions:** Sorting by amplitude rather than phase is advantageous when the breathing signal is irregular. However, to maintain spatial resolution, bin size must be adjusted for tumor velocity, which can be accomplished with VBAS. This method proved to be the most effective in terms of volumetric analysis and reproducibility.

Therapy Continuing Education Course — Room 224 A

CE: Quality Assurance for IMRT and IGRT

TH-C-224A-01

IMRT Patient QA

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Intensity modulated radiation therapy (*IMRT*) has become the standard-of-care for most cancer treatment programs. According to the 2004 AAPM professional information survey, 87 percent of the respondents had IMRT on one or more therapy units at their institution. The clinical successful or failure of an IMRT treatment program is dependant on the correct delivery of the 3D dose distributions calculated by the planning system (*Planned Dose*) to the correct location in the patient (*Delivered Dose*). There are many sources of error that can arise during IMRT planning and delivery. However, it is ultimately the responsibility of the Medical Physicist to ensure that the Planned Dose "agrees" with the Delivered Dose. The difference between Planned Dose and Delivered Dose (*i.e. Error*) in IMRT can originate from at least three different sources: 1.) The treatment planning model, 2.) Treatment delivery dosimetry and mechanics, and 3.) Time-dependant target/tissue positioning.

The IMRT treatment planning model must be evaluated as part of the initial IMRT commissioning, and again after major software upgrades. The IMRT model evaluation can be performed using geometric test plans, anthropomorphic phantom test plans, and patient test plans. Calculated and measured absolute and relative doses should be compared using multiple measurement techniques, such as film, ionization chambers, TLDs, diodes, electronic imaging devices, etc. The test plans and techniques should be similar to those that will be used in clinical practice.

The multileaf collimator and the linear accelerator must be evaluated for dosimetric and mechanical accuracy. IMRT test sequences can be used to evaluate leaf positional accuracy, time-dependant leaf positioning, motor performance, and dosimetry. These tests can be performed using film, ionization chambers, TLDs, diodes, electronic imaging devices, etc. In addition, patient-specific IMRT quality assurance should be performed for each patient to verify that the planned and delivered doses are within tolerance.

An additional source of error in IMRT is the uncertainty in the position and shape of the target volume. The use of image-guided radiation therapy can help minimize, but will not eliminate these errors. The impact of intra-fraction motion on IMRT delivery can be measured using a dynamic motion phantom to simulate clinical conditions. Film, ionization chambers, TLDs, or diode dosimeters can be placed in the dynamic phantom to directly measure the impact of motion on IMRT dosimetry.

This continuing education course will discuss commercially available dose measurement tools, phantoms, and techniques for performing acceptance testing, commissioning, and routine quality assurance for the IMRT process. The three classes of error will be discussed, with a special emphasis on the lessons learned and manpower requirements.

Educational Objectives:
1. To understand the issues surrounding IMRT quality assurance
2. To identify potential sources of errors in IMRT quality assurance
3. To review the tools used in IMRT quality assurance
4. To understand the impact of target localization and patient positioning on IMRT

TH-C-224A-02

QA for Linac KV Imaging Systems

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The recent commercialization of linac-mounted kilovoltage imaging systems (i.e., kV systems) has allowed high-precision verification and correction of patient position immediately prior to the delivery of radiation therapy using fluoroscopic, radiographic, or cone-beam tomographic modes. This novel technology challenges the radiotherapy community to redefine their patient positioning practice. One can now correct patient position using image information displaying not only bony anatomy and airways, like portal imaging, but also markers and soft tissue structures within the patient, including the target to be irradiated. On-line kilovoltage imaging further allows, using daily imaging sessions, on-line correction of patient translations and rotations, and the comparison for successive daily volumetric images permits to track changes of anatomy through the course of therapy. Introducing kV systems within busy radiation therapy clinics requires thoughtful testing and quality assurance protocols (QA) of the device, and judicious modification of existing radiation therapy processes and protocols.

The individual components making up kV systems are well-established technologies, and the quality assurance for each component follows accepted standards. However, the specific features of the integrated systems require particular attention. First, the kilovoltage beam may not share a common central axis with the megavoltage treatment beam; therefore, the relation of the kilovoltage imaging matrix to the megavoltage treatment beam must be monitored to ensure adequate localization, scaling, and geometric accuracy. Second, cone-beam tomography differs from conventional or helical CT imaging, and thus encounters specific image quality issues. A well-planned QA program integrates closely the kV system procedures with linac procedures described in accepted QA standards such as the AAPM task group 40 report.

This lecture will present a brief review of commercial systems, but will focus on a suitable QA program, with special emphasis on issues germane to the system and the clinical processes relying on its use. Examples of clinical use in a number of sites will also be presented.

Educational Objectives:
1. Understand the technical issues related to kV systems
2. Understand the impact of kV systems on clinical processes
3. Present a comprehensive commissioning protocol and QA program for kV systems.

This work is supported, in part, by a research grant from Elekta Oncology Systems.

Therapy Scientific Session — Room 230A

Therapy General

TH-C-230A-01

A Monte Carlo Investigation of the Temperature-Pressure Correction Factor for Kilovoltage X-Rays

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Purpose: To investigate the validity of the standard temperature-pressure correction factor (P_{TP}) for kilovoltage x-rays incident on various ionization chambers using Monte Carlo simulations of radiation transport. **Method and Materials:** The EGSnrc Monte Carlo computer code was used to calculate the response due to 20 kV, 40 kV and 60 kV beams as a function of chamber air density for thimble and spherical ionization chambers. The chambers studied had both graphite and C-552 plastic walls to investigate the effect of the wall material in addition to the dimensions of the cavity. In principle, the P_{TP}-corrected response is independent of air density. Thus, a breakdown of the P_{TP} correction factor is identified by any variation in the calculated response as the air density is varied. The air density associated

with the reference temperature and pressure conditions in North America (22 ºC, 101.325 kPa) is 1.205 kg/m^3. **Results:** At an air density of 1.0 kg/m^3, typical of Denver Colorado, the normalized P_{TP}-corrected response of a graphite-walled thimble chamber due to the 20 kV and 40 kV spectra is as much as 1.7% and 1.2% below the expected response, respectively. For a graphite spherical chamber at the same air density, the calculated response is 3.8% below unity for 40 kV and 60 kV beam qualities. Calculated responses of chambers with C-552 plastic walls are all within 0.5% of the expected response at air densities as low as 0.84 kg/m^3. Comparisons of calculated air kerma calibration coefficients at different air densities indicate that the breakdown of the P_{TP} correction factor should be easily detected experimentally. **Conclusion:** Variations in the P_{TP}-corrected response indicate that for low-energy x-rays the P_{TP} correction factor inadequately accounts for the dependence of ion chamber response on the temperature and pressure. Additional correction factors are therefore necessary under these circumstances.

TH-C-230A-02

A Carbon Nanotube Based Low LET Multi-Microbeam Array Singel Cell Iradiation System

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Purpose: Our long-term objective is to develop innovative carbon nanotube (CNT) based multi-pixel microbeam array system for single cell irradiation at small temporal scales and under direct microscope observation. The electron microbeam has an adjustable energy (20-60 keV) and dose rate. The microbeam l array can simultaneously irradiate a large number of individually selected cells *in vitro*, instead of sequentially irradiating cells one at a time using a single radiation source. From its 2,500 or more individually controllable microbeam pixels, the device offers flexibility in irradiation pattern that can be spatially discrete or uniform and temporally continuous or pulsed. Together with new advances in biosensors and cellular imaging, the proposed device can play an important role in understanding critical signaling events for both short and long term radiation effects occurring in cellular level immediately after irradiation. **Method and Materials:** The CNT single cell irradiation systems utilizes the unique field emission property of CNT, a quantum process that electrons escape from the metal surface under an external field. Each microbeam is generated by an individually controllable CNT pixel. The microbeam size is controlled by the Si_3Ni_4 electron/vacuum window and the dose rate is controlled by the external field. **Results:** We have fabricated the CNT field emission electron pixels, Si_3Ni_4 electron/vacuum windows, and a prototype single pixel CNT microbeam device. We have performed Monte Carlo (MC) simulation on the microbeam dosimetry and the effect of the Si_3Ni_4 window on the electron microbeam. Initial dosimetry measurement of the CNT microbeam irradiation using GARCHROMIC film and compared with the MC result. The prototype CNT system delivered a microbeam size of 20 micron and dose rate of ~5Gy/sec. **Conclusion:** Our preliminary data demonstrated that the CNT-based low LET microbeam system is feasible to deliver large dose rate and single cell (10-20 micron) microbeam irradiation.

TH-C-230A-03

A Complete MR-Based Treatment Planning Procedure for Radiotherapy of Intracranial Lesions

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Purpose: The purpose of this study is to develop a complete treatment planning procedure for radiotherapy of brain lesions based solely on magnetic resonance imaging. **Method and Materials:** The MR-based treatment planning procedure relies on converting the MR images into CT-like images by assigning electron density information to organ structures (i.e. brain, bone and scalp). First step in the process is to correct the MR images for 3D geometrical distortions by applying a novel distortion correction procedure. The next stage is to segment the datasets into anatomical structures by using an automatic segmentation tool suited for MR brain images. Once the MR images contain both the target volume and the electron density information, they are ready to be used for dose calculations. The resulting CT+MR and MR-based plans were compared in terms of isodose distributions, DVHs and NTCP/TCPs. A plan ranking TCP-based method for heterogeneous irradiation, which does not require the knowledge of radiobiological parameters, is used. **Results:** For all patients investigated, we found that MR-based plans (1.5T and 3T) are in good agreement (within 1%) with their corresponding CT+MR-based plans in terms of PTV dose coverage, DVHs and NTCP/TCPs. We compared tumor contours drawn on both 1.5T and 3T MR images in terms of shape, volumes and their impact on CRT plans. For all patients the delineation of the tumor was simpler for 3T images due to higher contrast. For some patients the tumor volumes drawn on the 3T images were up to 60% higher than on 1.5T images. RT plan ranking shows that the 3T plans are significantly better than 1.5T ones. **Conclusion:** The proposed MR-based treatment planning procedure was found to perform as good as the current clinical procedure based on CT+MR. Due to a higher contrast the tumor may be significantly better delineated on 3T images.

TH-C-230A-04

Characterizing a Monochromatic X-Ray Beam From a 1.3 GeV Synchrotron for Auger Electron Radiotherapy and Dosimetry Studies

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Purpose: Auger electron radiotherapy and dosimetry methods are being studied in preparation for future small animal irradiations using monochromatic x-ray beams and IUdR. Aims of the present study are: (1) establish methods for characterizing the LSU CAMD synchrotron monochromatic x-ray beam and (2) validate MCNP dose calculations in polymethylmethacrylate (PMMA). **Method and Materials:** The synchrotron's tunable (6-40 keV), monochromatic beam was set to 15 keV and collimated to ≈2.5-mm wide. Beam energy was determined from photons Compton scattered by a 56 mg·cm^{-2} aluminum target, whose energy was measured using a thin window 1-mm thick × 2.54-cm diameter NaI(Tl) scintillation detector. Beam cross section and divergence were measured using radiochromic film digitized with an Epson 1680 scanner. Depth-dose measurements within a PMMA phantom were made using a 0.23 cm^3 air-ionization chamber. Ionization was converted to dose in air and PMMA at each depth and a percent depth-dose curve generated. Results of MCNP5 Monte Carlo dose calculations simulating measured conditions were compared with measured data. **Results:** Measurements indicated the nominal 15 keV beam had energy of 15.5 keV, horizontal width of 3.1 cm, Gaussian distribution vertically with FWHM = 0.1 cm, and beam divergence <0.004 horizontally and vertically. A dose rate of 69 cGy·s^{-1}, measured at 0.58-cm depth in PMMA with 92 mA beam current, corresponds to 3.4×10^{11} photons·cm^{-2}·s^{-1}. Measured percent depth-dose curve agreed with MCNP5 simulated curve, yielding a PMMA mass attenuation coefficient of 1.1 cm^2 g^{-1}, approximately equal to the NIST value. **Conclusion:** The LSU CAMD 15-keV monochromatic beam has been characterized demonstrating utility of the measurement methods for future studies at energies suitable for iodine k-edge capture (>33.2 keV). MCNP5 Monte Carlo calculations have been shown to predict depth dose in PMMA validating its use and showing its potential for future treatment planning dose calculations in small animals.

TH-C-230A-05

Neutron Scattered Dose Equivalent to a Fetus From Proton Radiotherapy of the Mother

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Scattered neutron dose equivalent to a representative point for a fetus is evaluated in an anthropomorphic phantom of the mother undergoing proton radiotherapy. The effect on scattered neutron dose equivalent to the fetus of changing the incident proton beam energy, aperture size, beam location, and air gap between the beam delivery snout and skin was studied for both a small field snout and a large field snout. Measurements of the fetus scattered neutron dose equivalent were made by placing a neutron bubble detector 10 cm below the umbilicus of an anthropomorphic Rando® phantom enhanced by a wax bolus to simulate a second trimester pregnancy. The neutron dose equivalent in milliSieverts per proton treatment Gray increased with incident proton energy and decreased with aperture size, distance of the fetus representative point from the field edge, and increasing air gap. Neutron dose equivalent to the fetus varied from 0.025 to 0.450 mSv per proton Gray for the small field snout and from

0.097 to 0.871 mSv per proton Gray for the large field snout. There is likely to be no excess risk to the fetus of severe mental retardation for a typical proton treatment of 80 Gray to the mother since the scattered neutron dose to the fetus of 69.7 mSv is well below the estimated radiation absorbed dose threshold of 600 mGy observed for the occurrence of severe mental retardation in prenatally exposed Japanese atomic bomb survivors. However based on the linear no threshold hypothesis and this same typical treatment for the mother, the excess risk to the fetus of radiation induced cancer death in the first 10 years of life is 17.4 per 10,000 children.

TH-C-230A-06

High-Energy Proton Acceleration Driven by Ultra-Intense Ultra-Clean Laser Pulses

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Purpose: To improve the contrast ratio of the multi-terawatt Chirped-Pulse Amplification (CPA) Ti:Sapphire laser to 10^{11} to allow Coulomb explosion regime of ion acceleration in the interaction of ultra-short high-intensity laser pulses with ultra-thin (< 1 micron) foils. **Method and Materials:** The cross-polarized wave generation (XPW) technique in BaF_2 crystals was implemented. This technique improves contrast by rejecting the low-intensity amplified spontaneous emission (ASE) preceding the main laser pulse. Particle-in-cell (PIC) simulations were conducted under the anticipated experimental conditions: 225 TW in a 6.75 J, 30 fs laser pulse with no prepulse, focused to a spot size of 2.4 microns (FWHM) on thin foils of varying thickness. **Results:** Implementation of the cross-polarized wave generation technique resulted in a contrast improvement of three orders of magnitude to approximately 10^{11}. The performed PIC simulations show that for a 0.2 μm thick hydrogen foil, protons with energy of about 200 MeV can be generated. In the case of the two-layer aluminum-hydrogen foil the maximum energy of accelerated protons is about 150 MeV, but the proton spectrum has a flatter distribution, which may be more advantageous for therapy applications. **Conclusion:** We demonstrated that pulse cleaning based on cross-polarized wave generation (XPW) using two BaF_2 crystals yields a 10^{11} contrast ratio for a 50 TW laser system. Such contrast may be sufficient for a preplasma-free interaction of sub-Petawatt laser pulses with a sub-micron thickness foils at intensity of ~10^{22} W/cm^2. Modeling of this interaction with PIC simulations demonstrated proton energies that are of interest for the radiation therapy.

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TH-C-230A-07

Reconstruction of Spatially Varying Optical Properties of Human Prostate During Metexafin Lutetium PDT

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Purpose: The purpose of this study is to characterize the internal optical absorption and reduced scattering distribution of human prostate during the interstitial metexafin lutetium photodynamic therapy (PDT). These distributions could be utilized in PDT treatment planning, which optimizes the arrangement and weighting of interstitial light sources to ensure sufficient photon are delivered to the treatment volume. **Method and Materials:** A continuous-wave diffuse optical tomography system has been developed using a finite element reconstruction algorithm based on diffusion approximation of light distribution in biological tissue. Reconstructed images are presented from simulated data and clinical data acquired from prostate cancer patient being treated by PDT. Source-detector arrangement is identical in simulated data and patient data. The contour of prostate was obtained using ultrasound imaging. The meshes were generated by MATLab PDE Toolbox. **Results:** The synthetic measurement data were calculated for a rectangular phantom containing a single absorption anomaly and a single scattering anomaly. The model had a background of μ_a=0.03mm^{-1}, μ'_s=1.4mm^{-1}. The absorption anomaly was located at (15mm,15mm), with a radius 5mm, μ_a=0.06mm^{-1}; the scattering anomaly was located at (35mm,10mm), with a radius 5mm, μ'_s=2.0mm^{-1}.A total number of 5 sources and 12 detectors yielded 60 measurements (12 detectors ×5 sources). The reconstruction basis uses a coarser mesh (100 nodes) to reduce the degree of freedom. The reconstruction images successfully recover the both anomalies with good localization. The clinical DOT imaging was performed on 70-year old male subject. The reconstructed prostate μ_a varied between 0.025 and 0.07 mm^{-1} and μ'_s ranged from 1.1 to 2 mm^{-1}. These results are consistent with previous measurement using a point-by-point method.**Conclusion:** We have shown that this modeling and reconstruction algorithm can produce fast and reliable images of internal optical properties with fast computation time.

TH-C-230A-08

A Prototype Rotational Immobilization System for a Proposed Static-Gantry MicroRT Device with Tomographic Capabilities

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Purpose: Proposed small animal irradiation devices are typically isocentric gantry systems. Multi-axis gantry systems require significant resources to develop and maintain. A static gantry system could provide the functionality of a multi-axis gantry via subject rotation if subject motion could be minimized. In this study, we evaluated internal organ motion of mice within a prototype immobilization device during rotation. **Method and Materials:** Mice were anesthetized and immobilized in a prototype device designed to rigidly support animal positioning during rotation along the cranio-caudal axis. The head and tail of the mouse were allowed to extend beyond the immobilization device as an internal control. Validation of internal and external immobilization was assessed using computed tomography imaging at multiple rotation angles. CT images were co-registered (translated/rotated) using our research treatment planning system (CERR) into a common reference frame. Internal organ motion was assessed qualitatively by examination of internal anatomy in overlaid multi-plane CT images. Quantitative evaluation of organ motion was assessed by delineating organ structures in CERR and comparing relative organ volumes and centers of mass. **Results:** CT imaging demonstrated minimal exterior contour changes (<1mm) in the immobilized regions during rotation. Un-immobilized regions demonstrated the expected gravitational positional changes. Internal organs demonstrated sub-millimeter changes in organ centers of mass (heart and lung) and small (<5 mm3) changes in volume during rotation. These variations were similar to the differences when the same CT was re-contoured multiple times by the same operator and likely represent intra-observer contouring variations. **Conclusion:** A microRT device with a stationary irradiator, collimator, tomographic imaging system, and rotating subject would reduce the overall cost and complexity of the unit. This study demonstrates rotational immobilization of small animals is feasible.

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TH-C-230A-09

Implementation of MINERVA/PEREGRINE as An ATC Review Tool

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Purpose: To test the feasibility of a system of software (MINERVA/PEREGRINE) developed by the Idaho National Laboratory (INL) and the Lawrence Livermore National Laboratory (LLNL) for supporting quality assurance (QA) review of cooperative-group clinical trials treatment planning data within the Advanced Technology QA Consortium (ATC). **Method and Materials:** MINERVA is an open architecture, open source code system, designed to accommodate any computation engine through a plugin structure. MINERVA supports two types of data storage - relational databases and XML files. Patient data is stored in a relational database. XML-based import/export tools have been developed to transfer patient information between QA Centers and reviewers. Tools have been implemented as plugins to allow addition of more advanced tools. The research version of the LLNL PEREGRINE Monte Carlo code has been relocated to UC Davis Medical Center. The basis has been created for an integration of PEREGRINE with ITC, and it has been integrated with MINERVA as a calculation engine. **Results:**

MINERVA supports submission of digital treatment planning data using RTOG format. Ability to import DICOM-RT objects that satisfies the ATC DICOM conformance statement is needed. MINERVA provides display of DVHs and axial patient images with overlaid organ-at-risk/target-volume contours, as well as user-defined isodose curves. Users can edit contours, recalculate DVHs for these user-defined structures, and display point doses. Test cases for several body sites have been calculated using PEREGRINE to demonstrate feasibility. We believe that the use of Monte Carlo simulation will become a key tool for credentialing and QA review of clinical trials treatment planning and verification data in the near future. **Conclusion:** The MINERVA/PEREGRINE software system appears to be well suited to meet the needs regarding QA of data submitted for future ATC-supported clinical trials. **Conflict of Interest:** This work was supported by NIH U24 Grant CA81647.

TH-C-230A-10

A General Software Framework for Investigations in Radiation Therapy Planning

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Purpose: To be able to experiment with various topics in advanced radiation therapy planning using a stand-alone Windows-based software. **Method and Materials:** Product code for IMRT planning was merged with research code for adaptive radiation therapy and dose computations. An architecture and graphical user interface tailor-made for representing adaptive treatments was designed. Code for proton dose computation and treatment planning was developed and integrated into the system. **Results:** A software package that executes on a standard PC or advanced laptop has been developed. The system is capable of IMRT treatment planning using dose-volume based functions, EUD, Poisson-LQ and LKB biological models, both as objectives and hard constraints. Pencil beam and heterogeneity corrected collapsed cone dose computations can be used. The system can optimize every relevant combination of pencil beam weights, SMLC segments, gantry, couch and collimator angles. It is possible to perform intensity modulated proton therapy planning. Models for tumor repopulation and repair are included and irregularities in the fractionation scheme can be compensated for by allowing the dose to vary between fractions during optimization. The system exhibits a comprehensive GUI and functionality for simulation and evaluation of adaptive/IGRT treatments with algorithms for deformable dose accumulation based on information from portal imaging and 3D imaging modalities such as onboard CT scanners. Errors due to patient setup and organ motion can be counteracted and compensated for by couch shift and on- and offline IMRT replanning. **Conclusion:** A software environment suitable for studying various advanced topics in modern radiation therapy has been developed. The system has proven useful in research and development in IMRT optimization, biological models, proton therapy and adaptive radiation therapy. **Conflict of Interest:** The authors are employees and stock owners of the submitting company.

Therapy Scientific Session Room 224 C

Radiobiology I

TH-C-224C-01

Relative Biological Effectiveness(RBE) and Dosimetry of Low Energy Photons(8keV) Generated Using Miniature X-Ray Tubes

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Purpose: To study the Relative Biological Effectiveness(RBE) and dosimetric characteristics of an 8keV photon beam generated by an insertable miniature electronic brachytherapy device developed by Advanced X-ray Technology, Inc.(AXT). **Method and Materials:** The AXT X-ray needle consists of a primary conventional X-ray tube with silver anode producing a 22 keV beam focused through a collimator into the applicator needle which has a secondary copper target generating an 8 keV fluorescent beam. The radio-resistant human tumor cell lines HGL21(glioblastoma) and MCF7 (breast) were irradiated at 22^{o}C using the AXT miniature needle and compared with a Co-60 beam at dose rates of approximately 6cGy/min and 12cGy/min. An extrapolation chamber was used in gradient mode to determine the dose rate within the AXT beam after initially determining the effective area of the collecting electrode in a Co-60 beam using the Bragg-Gray relationship. **Results:** Cell surviving fraction (SF) was the primary end point in assessing the radiobiological effect. For the 8 keV beam, SF was found to be 0.056 for HGL21 and 0.018 for MCF7 for a dose of 2 Gy. This yields an RBE of 4.4 for HGL21 and 5.5 for MCF7 cells lines. The dose rate in the 8keV beam was found to vary linearly as a function of extrapolation chamber electrode spacing. This allows the use of the slope of the ionization gradient to determine the dose. The dose rate measured in free space at the location where the cells were irradiated was found to be 15.4 cGy/min.**Conclusion:** These high RBE values are not surprising given the stopping power of the very low energy recoil electrons produced in this beam, and support the premise that the AXT device will be an effective tool to treat tumor sites like brain, breast and prostate in which radio-resistance might limit conventional radiotherapy.

TH-C-224C-02

MicroRT/microRTP: A Conformal Small Animal Planning and Irradiation System

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Purpose: We have developed a novel small animal radiation therapy device (microRT), which integrates multi-modality imaging, radiation treatment planning, and conformal radiation therapy. In this study, we evaluated the accuracy of the treatment planning and positioning systems of the microRT device. **Method and Materials:** The microRT system utilizes a clinical ^{192}Ir HDR source collimated via machined tungsten inserts to deliver photon beams at a source to target distances of 1-8cm at four angles (0, 90, 180, and 270). Beams were modeled using Monte Carlo and a parameterized analytic dose engine was created. Radiochromic film (5mm steps) in a solid water phantom was used to evaluate actual delivered doses in multiple planes. Treatment plans using these beams were created by a custom treatment planning system (microRTP) based on imported fiducial-registered imaging (CT, MR, PET) of animals immobilized in the treatment position. A three-axis computer-controlled stage supports and positions animals in the beams according to the microRTP plan. Validation of the positioning system was performed using a phantom and images of phantom and collimator via a kV C-arm. **Results:** The analytic dose model agreed with the Monte-Carlo predicted dose within 5% and 10% outside and inside the 1 mm deep build-up regions, respectively. Film dosimetry agreed with the analytic model within 10% and also demonstrated an effective field diameter of 8mm at 17mm from the source. The ^{192}Ir line source geometry caused a radial anisotropy of up to 12% at 17 mm depth from the source. The positioning accuracy of the animal support hardware was sub-millimeter. **Conclusions:** The microRT system provides conformal radiation therapy based on pre-treatment imaging and planning for small animal models of cancer and tissue injury.

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TH-C-224C-03

EUCLID: A New Outcome Analysis Tool for High-Dimensional Clinical Studies

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Purpose: To develop a clinical outcome statistical analysis tool available for clinicians and researchers to perform univariate and multivariate analysis of a clinical study with a possibly large number of clinical, biological, physiological and dose-volume variables. **Method and Materials:** The program was developed using the MATLAB software. The bases for this work were laid out in the DREXLER software, developed at Washington University. New functions were added, including data histogramming and equivalent doses calculations (EUD, gEUD, BED), as well as the possibility to apply a threshold on variables to select a subset

of patients. A new user interface was developed with the goal of allowing easy manipulation and analyzing of large clinical studies along with the graphical and tabular reporting of outcomes and correlations with useful statistical information. **Results:** EUCLID provides a user-friendly graphical interface that allows several aspects of the analysis at the same time, using several windows. The input data can include for every patient an unlimited number of clinical, biological, physiological variables, outcomes and dose-volume histogram (DVH) points. The univariate analysis includes plotting and histogramming the variables individually. If survival time is available, the Kaplan-Meier method is used to calculate the survival curve. The multivariate analysis allows the user to show a map of correlation coefficients between all possible pairs of variables. The user may also perform a logistic regression analysis to use clinical and DVH variables to predict an outcome. The predictive power of the model can be visualized on a cumulative probability histogram, contour plot, octile plot or Receiver-Operating Characteristic (ROC) curve. If DVH data are present, the DVH can be displayed, and the TCP, NTCP and equivalent doses can be analyzed. **Conclusion:** EUCLID is a powerful, user-friendly tool that allows researchers to quickly obtain a complete statistical analysis of potentially large clinical studies.

TH-C-224C-04

Radiobiological Concerns On Prolonged IMRT Delivery for Head-And-Neck Carcinoma

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Purpose: Radiobiological effect of the prolonged IMRT delivery time on head-and-neck cancer has remain to be defined. The purpose of this work is to estimate a plausible set of radiobiological parameters (α/β, sublethal damage repair halftime, potential doubling time) for squamous cell carcinomas of head-and-neck (SCCHN) based on in vitro measurement and clinical data, and to examine the potential radiobiological influence due to the prolonged delivery time using the newly estimated parameters of SCCHN. **Methods and Materials:** In vitro cell survival measurements were performed for two cell lines of SCCHN irradiated by a series of specially-designed single and split dose regimens using a 6 MV machine. The obtained survival data were fitted to the Linear-Quadratic (LQ) model using the least χ^2 technique. Other radiobiological models, such as equivalent uniformly dose (EUD) and tumor control probability (TCP), were used to analyze published clinical outcome to validate the parameters estimated from the in vitro data. **Results:** Based on the present in vitro measurements, we have estimated a set of radiobiological parameters for SCCHN: repair half-time $T_r = 16 \pm 21$ min, the potential doubling time $T_d = 48 \pm 10$ hours, radiosensitivity parameters $\alpha/\beta = 7.9 \pm 4.5$ Gy, $\alpha = 0.22 \pm 0.08$ Gy. This set of parameters was found to be able to fit the available clinical data. The calculation based on these parameters indicated that prolonged delivery time, if comparable/longer with the repair half-time, would result in noticeable reduction in treatment effectiveness. For example, an IMRT delivery time of 30 minutes would result in a reduction of 11% in tumor EUD (compared to a 5-minute fraction). **Conclusions:** The present measurement and analysis show that the repair half-time and potential doubling time for head-and-neck cancer are relatively short, indicating that optimal IMRT delivery time needs to be clinically considered.

TH-C-224C-05

Analysis of Radiation-Induced Pneumonitis in Lung Cancer Patients

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Purpose: To study clinical, physiological, biological and dose-volume factors in lung cancer patients who developed symptomatic radiation-induced pneumonitis (RP). **Method and Materials:** Data from two-hundred patients with non-small cell lung cancer who received 3D conformal radiotherapy (RT) treatment were analyzed using an in-house developed MATLAB-based analysis tool, EUCLID. The effect of 52 clinical, physiological and biological factors, as well as dosimetric variables extracted from the lung dose-volume histogram (DVH) was analyzed using univariate and multivariate approaches. **Results:** Thirty nine patients (19%) developed RP. In the univariate analysis, the forced expiratory volume in 1 second (FEV1) post-treatment, normal tissue complication probability (NTCP), mean lung dose, history of smoking, level of TGF-β post-treatment and nodal stage were associated with RP (*p*-range 0.001-0.033). When considering the percentage of volume of lung receiving more than a specified dose, we found that 60 Gy (V60) yields the strongest correlation with RP (p=0.0001). In the multivariate analysis, a logistic regression analysis was performed using different sets of uncorrelated variables. The predictive power of the model was quantified using the area under the Receiver-Operating Characteristic (ROC) curve. The best result was obtained with V30, FEV1, age, time of chemotherapy (before, after or concurrent with RT) and Lobe (location of tumor inside the lung). The area under the curve for these variables was 0.85. While only the regression coefficients of V30 and FEV1 determined a correlation with RP with a p-value less than 0.05, the exclusion of the other three variables led to a lower area under the curve. **Conclusion:** V30 and FEV1 were the best predictors of symptomatic RP after external beam RT for lung cancer. Multivariate analysis showed that other clinical factors that are not individually strongly associated with RT can be included in a regression model to increase the predictive power of that model.

TH-C-224C-06

Using Quality of Life Information to Rationally Incorporate Normal Tissue Effects Into Treatment Plan Evaluation and Scoring

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Purpose: Modern radiotherapy treatment planning systems provide an increasing number of competing plans. The decision to select a particular plan for treatment is generally made by a radiation oncologist based on training and clinical experience. The criteria applied are often poorly-defined, qualitative, and largely based on tradition and familiarity. A "realistic" approach utilizing decision analysis tools to evaluate/rank treatment plans based on quality adjusted life years (QALY) expectancy was developed. **Method and Materials:** The decision analysis methods were applied to the concept of uncomplicated tumor control probability (UTCP). The expected outcome for an anticipated course of radiation was described as a series of probabilities: alive, free of disease without complication; alive with disease; alive with complication, etc. For each of these states of health, a utility can be assigned based on published work or empirical estimates. The total QALY's for a particular treatment plan represent the product of duration-weighted states of health. The formalism for UTCP was generalized to incorporate the total QALY ($UTCP_{QALY}$) for a particular treatment. **Results:** This approach was applied to compare the clinical treatment plans of 200 patients who received high-dose external-beam for unresectable non-small cell lung cancer. Thirty nine out of the 200 patients developed radiation-induced pneumonitis with the grade distribution of 8.7%, 69.6%, and 21.7% for grades 1, 2, and 3, respectively. The plan ranking based on the traditional UTCP and pneumonitis QALY-weighted UTCP ($UTCP_{QALY}$) values were different. The UTCP varied significantly, reaching values of 0.5. Using $UTCP_{QALY}$ scoring, the mild complications importance is downplayed compared to the severe complications, with all $UTCP_{QALY}$ values above 0.85. The QALY-weighted UTCP's appear to provide better clinical realistic differentiator between plans. **Conclusion:** The construct presented represents a potential improvement in the current methods used to compare plans. Formulas presented can be readily incorporated into planning systems.

TH-C-224C-07

EUD-Assessed Impacts of Respiratory Motion On Breast Irradiation

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Purpose: Respiration results in intrafractional motion and anatomic changes for both target and normal structures (e.g., lung, heart) during the radiation treatment for breast cancer. The purpose of this work is to quantify the dosimetric and radiobiological impacts using the concept of equivalent uniform dose (EUD). **Method and Materials:** Intrafractional variations were assessed based on 4DCT datasets acquired using a GE LightSpeed-RT scanner and Varian RPM-respiratory-gating system. The 4DCT datasets along with the conventional 3DCT images for 10 patients were analyzed retrospectively. Each set of 4DCT consisted of 10 CT image sets at a phase between 0-90% during one respiration cycle. For each case, a 3D dosimetric plan of two tangential beams irradiating the whole breast was generated based on the 3DCT images using Xio (CMS) planning system. The parameters for this dosimetric plan (e.g., energy, beam angles,

beam shape, wedge, weighting, isocenter location) were copied to each phase image set of the 4DCT to generated 3D dose distribution. DVHs for each phase image set were generated and were used for EUD calculation based on LQ model for breast tumor and Lyman model for lung. **Results:** 4DCT showed breast position/shape and lung position/shape/volume are changed with respiration. For example, lung volume changed up to 20% for the cases studied. These changes result in significant intrafractional variations in dose distributions/DVHs. Our calculations show that, compared to the planned EUD (based on the 3DCT), the breast EUD was lowered by an average of 5% (when including all 10 breathing phases) and up to 10% (at a particular phase). Lung EUD varied by ±3% during respiration. **Conclusion:** Respiratory motion in breast radiation treatment can potentially result in decreased target coverage and normal structure sparing. This effect that can be assessed using EUD, and decreased EUD may be an indicator for gated breast irradiation.

TH-C-224C-08

Estimating Differences in Volumetric Bone Growth by Treatment Method

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Purpose: To estimate potential differences in volumetric bone growth in children with sarcoma treated with intensity-modulated (IMRT) and conformal (CRT) radiation therapy using an empiric dose-effect model.
Methods: Volumetric bone growth was estimated 4 years after radiation therapy for 36 pelvic bones (ischio-pubis and ilium) from 11 patients using a random coefficient model for flat bone growth that incorporated patients age, pre-RT bone volume, integral bone dose >35Gy, and time after completion of RT. Dosimetry representing the actual CRT/IMRT plan, a non-treated comparable IMRT/CRT plan and an idealized plan delivering dose only to the PTV, with no dose delivered to tissue outside the PTV, were entered into the model and the resultant volumes compared relative to modeled normal bone growth (integral dose of zero). The prescribed dose to the PTV ranged from 36-55.8 Gy and the median values for the PTV and studied bone volumes were 774 ml (147-1964 ml) and 76 ml (14-215 ml), respectively. **Results:** Relative to normal bone growth, patients were predicted to maintain 93%, 87% and 84% (p=0.06) of their expected growth with idealized, IMRT and CRT approaches, respectively. Older patients, age ≥10 years were predicted to maintain a mean growth of 98% compared to normal regardless of method. Those age < 10 years maintained 87% (idealized), 76% (IMRT) and 70% (CRT) of expected growth (p=0.015). On post hoc testing (Tukey) CRT and IMRT both differed significantly from idealized but not from one another. **Conclusions:** Linear dose-effect models facilitate comparison of treatment methods and potentially interventions. For older patients, treatment methods do not significantly impact growth for specific flat bones; however, for younger patients, treatment methods may significantly impact flat bone growth especially as we move towards idealized dose distributions potentially feasible with particle therapy.

TH-C-224C-09

Using SPECT-Guidance to Reduce Intensity Modulated Radiation Therapy (IMRT) Dose to Functioning Lung

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Purpose: Single photon emission computed tomography (SPECT) provides a map of the spatial distribution of lung perfusion. Thus, SPECT guidance can be used to deliberately divert dose away from higher functioning lung, thereby potentially reducing lung toxicity. This work presents an algorithmic methodology for achieving this aim, and tests it in intensity modulated radiotherapy (IMRT) treatment planning of five randomly selected lung cancer patients. **Method and Materials:** IMRT treatment plans were generated with and without SPECT guidance and compared. Both sets of plans were made to adhere to the same dose-volume constraints. The SPECT-guided process works by segmenting healthy lung into four regions on the basis of SPECT intensity, and sequentially allowing dose to the target via regions of increasing SPECT intensity. This process results in reduction of dose to functional lung, reflected in the dose-function histogram (DFH). DFHs quantify the percentage of total function above dose levels. The plans were compared using DFHs and F_{20} / F_{30} values (F_x is the functional lung receiving dose above x Gy; 20/30 Gy are significant thresholds for radiation pneumonitis). **Results:** In all cases, the SPECT-guided plan produced a more favorable DFH compared to the non-SPECT guided plan. Additionally, the F_{20} and F_{30} values were reduced for all patients by an average of 13.6% ± 5.2% and 10.5% ± 5.8%, respectively. In all patients, for the SPECT-guided plans, DFHs of the two highest functioning SPECT regions were reduced while DFHs of the two lower functioning regions were increased, illustrating the dose "give-take" between SPECT regions that is inherent to the redistribution process. **Conclusion:** SPECT-guided IMRT shows potential for reducing the dose delivered to highly functional lung regions. This dose reduction could reduce the number of high grade pneumonitis cases that develop after radiation treatment and improve patient quality of life.

Therapy Symposium Valencia A

Symposium in Memoriam of Robert Loevinger: How Accurately Can We Measure Dose Clinically?

TH-C-ValA-01

Memorial Lecture for Robert Loevinger

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How perfectly appropriate is the Symposium: "How accurately can we measure dose clinically?" to memorialize Bob Loevinger. The clear threads in Bob's career and seminal work was his quest for improved accuracy in dosimetry measurements, his organization of calibration networks to transfer traceable measurement standards to the clinical physicist, and his development of protocols and formalisms to implement accurate measurements of dose at the clinical level. In his professional career of some 55 years, his contributions were many and important. Quiet and unassuming, Bob was the supreme dosimetrist: he designed and constructed extrapolation chambers for beta dosimetry in his early career, and then the Wide-Angle-Free-Air-Chamber (WAFAC) for prostate-seed dosimetry in his late career; he developed the MIRD schema with Mones Berman for dose calculations in nuclear medicine, and led the development of the TG 21 protocol for the determination of absorbed dose from high-energy photon and electron beams; at the IAEA in the 1960s he was instrumental in the creation of their Dosimetry Laboratory and the IAEA/WHO Secondary Standards Dosimetry Laboratory Network that serve the mostly developing member states, and initiated their postal dosimetry service to clinics in the member states; then at the NBS in the 1970s he worked with the AAPM (he was a charter member) to create the network of Accredited Calibration Dosimetry Laboratories to better disseminate US radiation measurement standards to the clinical community in North America. Much of his work was recognized during his lifetime by numerous awards given him by many organizations, but I think he would be most honored by this Symposium, which gathers like-minded scientists to discuss issues on which he spent his career.

TH-C-ValA-02

In's and Out's of Non-Equilibrium Dosimetry

J Seuntjens*, McGill University, Montreal, QC, CA

Typical procedures for clinical dosimetry are well established for measurements in charged particle equilibrium situations. These situations only form a subset of the measurement challenges of a clinical physicist. Dose measurements in regions of charged particle disequilibrium require special considerations before the measurement can be assumed accurate. These disequilibrium conditions occur in association with measurements performed for standard clinical treatment techniques as well as for special treatment techniques. In the symposium we identified four major areas that complicate accurate clinical dosimetry: (1) the photon build-up region, (2) narrow photon beams, (3) measurements in heterogeneous phantoms and (4) modulated fields and dynamic measurements.
In the present lecture we describe the principles of accurate dose measurements in general in equilibrium and non-equilibrium situations. Principles of detector response, energy dependence and characteristics of practical detectors are described with emphasis on the understanding of detector behaviour in non-equilibrium conditions. By way of introduction, practical examples will be provided of non-equilibrium measurements in the build-up region, narrow beams, heterogeneous phantoms and IMRT beams. The lecture will provide general guidelines about detector

suitability for commercially available devices for the discussed areas of application. Finally, uncertainties of the procedures in a clinical context will be discussed.

Educational Objectives:
1. To understand the fundamental complications of non-equilibrium measurements
2. To understand the impact of detector properties on measurement accuracy in non-equilibrium situations
3. To place measurement uncertainties in non-equilibrium conditions in a clinical perspective.

TH-C-ValA-03

Accurate Dosimetry in Narrow Stereotactic Photon Fields

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Dosimetric measurements for stereotactic radiosurgery or radiotherapy fields typically include determination of relative output factors, tissue maximum ratios and off-axis beam profiles. Accurate measurements of each of these quantities are made more difficult when the measured field sizes are either comparable to the detector size, or less than the distance required for lateral electronic equilibrium. These difficulties are present when measuring either single, static-field cone or micro-MLC linac-based delivery systems, or simultaneous multiple-field Gamma Knife delivery systems.

Several detector characteristics should be considered when choosing a measurement system. The detector size in the radial direction will determine the extent of the beam profile integrated in the reading. Typically solid-state detectors or film (radiographic or radiochromic) have been used to reduce this volume-averaging effect. Several other detection systems have also been used, including pin-point ionization chambers, thermoluminescence dosimetry, and diamond and scintillation detectors. Techniques exist to correct for finite detector volume, including the extrapolation of measured results to zero-volume, and deconvolution of measured data with the detector response function.

The detector energy response also should be considered due to the variation in the number of low energy scattered photons with field size and depth. Additionally, for field sizes below lateral electronic equilibrium, variations in the stopping power ratios affect the conversion of ionization to dose, particularly for higher-energy measurements. Both of these effects increase with beam energy and depth.

This lecture will provide an overview of the measurement techniques used to determine dosimetric quantities for stereotactic fields. Recommendations for measurement systems will be made, and limitations to each system will be discussed. Estimations of error will be provided, both for individual measurements and in the overall planned dose. When available, comparisons will be made with results predicted by theoretical Monte Carlo calculations.

Educational Objectives:
1. Understand the basic principles and practical aspects of clinical dosimetry for stereotactic radiosurgery.
2. Understand the limitations and applicability of various detector types and sizes for small field measurements.
3. Understand current techniques available to correct data measurements in small fields.

TH-C-ValA-04

Accurate Dosimetry in Photon Build-Up Region

W Abdel-Rahman*, S Devic, J Seuntjens, E Podgorsak, McGill Univ Health Center, Montreal, Quebec, CA

Accurate measurements in the dose build-up region for high energy photon beams are not easily obtained. While dosimetry in situations where electronic equilibrium exists is well understood, there is in general no consensus on the most accurate method for measuring doses in the build-up region. In the past, data acquired with an extrapolation chamber were regarded as the benchmark by which the data from other more commonly used dosimeters are evaluated. As extrapolation chambers are clinically impractical devices there is a need to study the behaviour of commercially available and clinically suitable detector systems for accurate dosimetry in the build-up region.

This lecture will provide an overview on the characteristics of the dose build-up region measurements for photon beams, the suitability of several clinical dosimeters for build-up dose measurement and limitations in measurement accuracy.

Educational Objectives:
1. Understanding the reasons why doe measurements in the build-up region are challenging.
2. Grasp issues of the suitability of several dosimeters for measurements in the dose build-up region.
3. Discussion of ongoing research on dosimetry in the dose build-up region.
4. Discussion of the associated uncertainties and their clinical relevance.

TH-C-ValA-05

Accurate Dose Measurements in Heterogeneous Phantoms

M Huq*, UPMC Cancer Center, Pittsburgh, PA

The human body consists of tissue types that have radiological properties that are different from water. These include, for example, lung, bone, and oral cavities. Presence of such tissue types and cavities in the treatment fields of high-energy photon beams creates potential dosimetric problems. For inhomogeneities with density less than that of water electronic disequilibrium situations can be severe. Lateral electronic disequilibrium is present for small field sizes (i.e., 5 cm x 5 cm) and high energy beams (i.e., 15 MV) in a low density inhomogeneity such as lung. Perturbations at air-tissue interfaces are complex to measure or calculate due to lack of electron equilibrium. The trend of data published in the literature show that for low density media i) dose generally increases beyond the depth of dose maximum; ii) build-up and build-down regions exist within tissue near the low density media-tissue interfaces; the severity of these effects increase with increasing energy and decreasing field size; iii) the penumbra increases with energy in the region of low density region. For high density media the dose is found to decrease beyond the depth of dose maximum.

The dosimetric effects of these heterogeneous tissues become even more complicated for IMRT beams. This is because i) small radiation beams are inherently difficult to measure; ii) standard ion chambers have dimensions that are large compared to the beam and do not have the spatial resolutions that are needed to resolve the narrow central region of uniform dose and the sharp dose gradient regions of the penumbra and iii) the chambers may have a dose rate dependence.

The dosimetric impact of the presence of heterogeneous tissues in megavoltage photon beams have been addressed with varying degrees of success by various investigators i) experimentally by the use of specially designed ionization chambers, film, TLD and other dosimeters in specially constructed phantoms, ii) theoretically by the development of various dose calculation algorithms and iii) by the use of Monte Carlo simulation.

Educational Objectives:

Develop an appreciation of
1. the challenges involved in accurate dose measurements in heterogeneous phantoms
2. the clinical implementation of the results of such measurements, various dose calculation algorithms and/or Monte Carlo simulations to various disease sites that involve the presence of various types of heterogeneous tissues.

TH-C-ValA-06

Accurate Dosimetry Measurements for IMRT and 4D Delivery

C Ma*, Fox Chase Cancer Center, Philadelphia, PA

The use of conformal radiotherapy, especially with the IMRT technique, is a major departure from the way radiotherapy is currently delivered. Although the use of multileaf collimator (MLC) provides the possibility of achieving better dose distributions conformed to tumor targets, it also increases the treatment complexity. The sequences of leaf movement and

their associated effects on the dose delivered to the patient may vary significantly depending on the accelerator and the MLC design. Accurate measurement of IMRT dose distributions in a clinical setting is not an easy task since many factors may affect the measurement results. In this presentation we will review various factors affecting IMRT dose distributions including the variation of the accelerator head scatter component in the MLC-collimated beam, the amount of photon leakage through the leaves, and the scatter from the leaf ends, the "tongue and groove" effect, and the effect of back-scattered photons from the moving jaws and MLC leaves on the monitor chamber signal. We will describe the use of different detectors commonly used for absolute and relative dose determination with both static and dynamic beam delivery. We will discuss the effects of electron disequilibrium, detector perturbation and patient heterogeneous anatomy on the measurement accuracy.

Below are the educational objectives of this presentation:
1. Review dosimeters for absolute and relative IMRT dose measurements
2. Discuss the process for dose determination under electron disequilibrium conditions
3. Describe the use of Monte Carlo simulations to derive detector correction factors
4. Discuss major factors affecting IMRT dose measurement accuracy

TH-C-ValA-07

Moderated Discussion & Concluding Remarks

J Seuntjens*, McGill University, Montreal, QC, CA

Radiation therapy is rapidly moving into the direction of image guidance, functional target volumes, hypofractionation, dose escalation and 4D deliveries. In this era of joint imaging-therapy developments, accurate dosimetry techniques albeit often overlooked, increasingly require dealings with complex charged particle disequilibrium measurements and their interpretation. In this symposium, clinical dose measurements have been reviewed with emphasis on accuracy in these charged particle disequilibrium conditions. After a brief introduction and review of fundamentals of dosimetry, clinical accuracy requirements, four distinct areas of dosimetry in charged particle disequilibrium and their clinical relevance have been discussed. Guided by the main conclusions of the contributions in the four areas, moderated discussions will be conducted around clinical relevance of dosimetric accuracy in on non-equilibrium conditions, detector suitability, technical aspects and other areas of application.

Workshop — Room 230 C

Mammography QA Workshop - I

TH-C-230C-01

Mammography QA Workshop I and II

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Purpose: to explore the impact of DR mammography on the practice of medical physics. Historical and new methods for providing scheduled and unscheduled mammography services for facilities using DR mammography will be presented. **Method and Materials:** clinical medical physics services provided for DR mammography facilities from various manufacturers will be presented. Quality control activities approved by the FDA for each individual manufacturer will be compared. The status of a proposed "Alternative Standard" to allow for a more uniform approach to medical physics mammography services will be reviewed. Case studies will be presented demonstrating methods and cost considerations for providing medical physics services under the "minimum standard" (prescribed by MQSA regulations) and "best practices" model. **Results:** Medical physics services provided in the "minimum standard" and "best practices" model have implications for the quality and cost of mammography services. **Conclusion:** Medical physics services may be provided in a professional and valuable manner, using combinations of the minimum standard of practice and the "best practices" model. The professional medical should consider multiple parameters when determining the appropriate model under which to deliver services.

Imaging Scientific Session — Room 330 A

Molecular / Functional Imaging

TH-D-330A-01

Annual Gamma Camera QC: Techniques And Phantoms To Simplify The Implementation Of The NEMA NU-1 Procedures For Tests Recommended By The ACR

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The objective of this work is to present techniques to perform the NEMA tests that are suggested by the ACR for annual gamma camera QC. Since the recommendation contains nine tests, the goal is to devise simple and efficient procedures to reduce the required time without compromising the quality. Also included is a comparison of test equipment conforming to NEMA specifications to equipment made in-house.

The time to complete the annual QC is markedly reduced by the availability of specifically designed phantoms. They provide a reliable means to compare the cameras and to establish a performance baseline. For two tests, Multi Window Spatial Registration and SPECT Resolution with scatter, the NEMA prescribed equipment is compared with readily available devices. The comparison of the commercial MWSP device and the one produced in-house showed that the average maximum difference of the center of mass for the three Ga-67 peaks measured at various points across the crystal face is 0.35 mm vs. 0.33 mm for the commercial and the in-house device, respectively. For the SPECT resolution using three capillary tubes filled with Tc-99m, a NEMA phantom is compared to a modified Jaszczak phantom. The FWHM is 4.78 pxl vs. 4.79 pxl (radial) and 4.144 pxl vs. 4.167 pxl (azimuthal) for NEMA and Jaszczak phantom, respectively.

Further topics include sensitivity, count rate performance, comparison of fit methods, and monitor/printer QC.

TH-D-330A-02

An Electronically-Collimated Gamma-Ray Detector for Intraoperative Localization of Radiation Sources

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Purpose: We are developing a radiation detector for locating radiation sources, e.g. for intraoperative localization of sentinel lymph nodes and metastases. The design emphasizes compact size and portability, wide field of view, and efficiency and accuracy in source localization. Room-temperature cadmium-zinc-telluride (CZT) detectors and electronic collimation via Compton-scatter detection are used to achieve the design goals. **Method and Materials:** The detector design was simulated in GEANT4 to assess feasibility and optimize the design. The simulation model was a 6-sided box with one detector module on each end and two modules per side. One end is the primary scatter detector; the other modules detect the scattered photons, operating in coincidence with the primary module. The simulations allowed variations of detector dimensions, pixel size, energy resolution, and source energies. Experimental measurements with a 3-module partial prototype were used to validate the simulations; each module is a 16x16-pixel 38x38x5-mm^3 CZT detector. **Results:** The simulations indicated ~15% of incident gamma rays produce valid direction measurements; 30-70% of these events are Compton-photoelectric interaction pairs. The measured angular resolution varied from a few degrees for 100-keV gamma-rays up to about 10° FWHM at 1 MeV. Above ~1.5 MeV, multiple Compton-scatter events limit accurate measurement of Compton cone angles; below ~50 keV, few Compton-scatter events occur. Experimental validation with the prototype system is in progress.**Conclusion:** Efficiency and angular resolution vary with source energy but reasonable performance seems achievable for radioisotopes from Am-241 through Co-60. Ongoing work is investigating the effect on performance of design parameters such as pixel size and detector thickness. Coupled with concurrent development of real-time methods to calculate the directional information, this system provides localization of radiation sources with high sensitivity. **Acknowledgment:** Supported by Homeland Security Advanced Research Projects Agency, and Space and Naval Warfare Systems Center San Diego; Contract N66001-05-C-6024

TH-D-330A-03

Development of a High Resolution Imaging System for Nuclear Medicine

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Purpose: To construct a diagnostic imaging system for nuclear medicine that can generate images with spatial resolutions of 1-2 mm and hence improve the image quality in diagnostic nuclear medicine**. Method and Materials:** Tumors of 1-2 mm can be detected using photon diffraction to focus the gamma rays emitted by the radiopharmaceutical in the tumor region onto a detector, much like using a magnifying glass to focus sunlight on a small area**.** The gamma rays from the tumor volume are focused by an array of lenses, each comprised of small copper crystals arranged in concentric rings of increasing diameter**.** Specific crystalline plane orientations can be used for each ring so that the diffracted gamma rays converge on a small area on a detector's sensitive region**.** No collimation is needed since each lens in the system will focus one gamma-ray energy at one time**. Results:** Preliminary data collected with a prototype lens using Co-57 and Tc-99m not only show that photon diffraction is a viable approach to focusing gamma rays, but yielded a spatial resolution of 3 mm**.** Sensitivity estimates based on these data indicate that a 9-lens array could detect a 1 μCi spherical source of 0.01cc in volume with a signal-to-noise ratio of 6-to-1**. Conclusion:** The use of photon diffraction in diagnostic imaging in nuclear medicine is a strong and innovative technique that only this imaging system possesses. Photon diffraction eliminates the need for external collimation, which is the cause of limited sensitivity in gamma and SPECT cameras, because the crystal elements in a lens prevent photons with energies other than the specified energy from reaching a detector. Finally, detection of a tumor site at its inception can allow for earlier initiation of treatment and wider treatment options which can potentially improve the chances of a cure.

TH-D-330A-04

A Novel PET Respiratory Gating Algorithm to Reduce Lung Tumor Blurring Using the 4D NCAT Phantom

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Purpose: Develop and validate a PET gating algorithm based on the amplitude of respiration to correct for abnormal respiratory cycles**. Method and Materials:** Using the 4D NCAT phantom model, 3D PET images were simulated in lung and other structures at different times within a respiratory cycle**.** To compare the amplitude gating algorithm with time gating, NCAT phantom was used to simulate a case with 5 different respiratory periods**.** We generated 6-10 frames over one respiratory cycle (corresponding to 3-5 s respiratory periods) and summed the results to mimic clinical imaging**.** Images were reconstructed with and without respiration motion**.** Comparison was performed for gated and un-gated images, and for the new amplitude binning algorithm with the time binning algorithm by calculating the mean number of counts in the ROI**.** Lesion-to-background ratios were 2.5, 5 and 8**.** Lesion diameters were 6 mm, 8.5 mm, 10 mm and 20 mm**.** Simulated images were created using a Gaussian distributed random number generator**.** Blurring due to the finite PET image resolution was simulated by the convolution of each slice with a Gaussian filter with FWHM of 1.6 pixel**. Results:** As both the L/B ratio and lesion size decreases, image degradation due to respiration increases**.** The greater benefit for smaller diameter lesion and lower L/B ratio indicates a potential improvement in detecting more problematic lesions**.** Little improvement is gained for large lesions with high L/B ratios**.** But these are relatively easy to diagnose and gating is probably not necessary**. Conclusion:** From the study made using 4D NCAT simulation, it was observed that in each selected ROI, the relative activity values in four cases are**:** Ideal PET images (without respiratory motion) > Amplitude Gated PET images > Time Gated PET images > Un-gated PET images, here greater value means better and more accurate lesion detection.

TH-D-330A-05

Modeling and Correcting for Respiratory Motion in PET

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Purpose: To model and correct for respiratory motion in PET **Method and Materials:** Regular arrays of lesions of different sizes and contrast were incorporated into the NCAT Torso phantom. SimSET was used to simulate data acquisition and data was reconstructed using the filtered back projection algorithm at 16 phases of the respiratory cycle. Affine registrations were performed on the images to create a single summed motion corrected PET frame. The transformations were derived from (i) the PET images themselves and (ii) simulated CT images at the same respiratory phases. **Results:** Respiratory motion both blurs lesions and decreases the accuracy of quantification of PET images. These effects varied with lesion size and SUV. Lesion size is seen to increase and uptake values decrease in lesions undergoing motion. Smaller and lower contrast lesions show more differences between static, time average and motion corrected frames. Preliminary comparisons between corrected and static frames show that the CT corrected frame is closer to the static frame than the PET corrected one. **Conclusion:** We have developed a complete simulation of the PET data acquisition and reconstruction process based on the NCAT and SIMSET software packages, to assess the effect of respiratory motion and our proposed motion correction technique on PET data. For the small number of lesions of sizes described here, the differences in volume and SUV confirm that respiratory motion both blurs lesions and decreases the accuracy of the quantification of PET images. The simulation and assessment methods above were used to evaluate motion correction methods used to correct simulated PET data. Results show that smaller and lower contrast lesions show more differences in volume and SUV between the corrected, static and time average frames. Future work will involve looking into ways to improve the correction scheme, and application of the technique to clinical data.

TH-D-330A-06

Registration of Gated PET Images Using Wavelet Denoising

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Objective: Gated PET images are characterized by low signal to noise ratio which results in poor image registration**.** The aim of this abstract is to evaluate the accuracy of image registration of gated PET images following wavelet denoising**. Methods:** A NEMA/IEC phantom containing 6 spheres of varying diameters (1-3.7cm) was filled with F-18 water and positioned on a unidirectional translating platform in the FOV of a DST PET/CT scanner**.** A sinusoidal waveform (5 sec cycle, 2cm peak to peak) was used to drive the platform during the PET data acquisition**.** The platform motion was tracked using an RPM device which sent a trigger signal to the PET scanner at a specific phase of every repeating cycle of the waveform**.** PET data was acquired in 2D for 30 minutes using LIST mode and then rebinned using a gated prescription (10 bins of 500 msec each) into 13 different scan durations ranging from 1 min to 30 min**.** This scheme resulted in 13 gated image sets each corresponding to a different scan duration**.** The same experiment was then repeated using four different sphere/background ratios of 2, 3.4, 7.4 and 13.5**.** PET images were then reconstructed using OSEM**.** At each contrast ratio and scan duration, the gated images were first processed using wavelet denoising and then registered to the first bin**.** The estimated motion from this registration was then compared to that without wavelet denoising as well as to the true motion**. Results:** Wavelet denoising decreases the background noise without blurring the image**.** The effect of wavelet denoising on image registration decreased with increasing sphere-to-background ratio and increasing scan duration**.** Plots showing the difference between image registration with and without wavelet denoising will be presented**. Conclusion:** Wavelet denoising improves image registration**.** This improvement quickly diminishes with increasing scan duration and/or contrast ratio.

TH-D-330A-07

Model-Based Statistical Image Reconstruction for 4D PET

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Purpose: Four-dimensional (4D) PET can be acquired with gated, dynamic or list mode**.** In reality, a major problem limiting its clinical application is the poor statistics, since the total coincidence counts in conventional 3D PET are divided into several phase bins and each of them is treated as an independent entity in 4D image reconstruction**.** We develop a mathematically rigorous system approach that allows one to maximally enhance the signal-to-noise ratio (SNR) of 4D PET by simultaneously considering the coincidences acquired at all time points when reconstructing the phase-resolved images. **Method and Materials:** A GE Discovery-ST PET/CT scanner was used to acquire 4D-CT/PET images**.** A Real-time Position Management (RPM) system was used to determine the respiration phases and to correlate temporally the PET and CT images**.** By deformable registration of the 4D-CT images, a *patient-specific* motion model was derived and incorporated into our "spatial-temporal PET reconstruction" algorithm based on the *maximum likelihood* principle**.** The approach was quantitatively evaluated with numerical and physical phantom experiments**.** Five clinical studies of pancreatic, lung and liver cancer patients were then carried out. **Results:** Via a novel concept of "virtual curved line-of-response", we proved that the PET "4D likelihood" can be maximized with a modified expectation-maximization algorithm**.** Numerical/physical phantom experiments and patient studies showed that the algorithm converged monotonically**.** In the former two cases, the "ground truths" were reached within 40 iterations, and the SNRs were enhanced by more than 80% over the regular 4D PET and 35% over 3D PET**.** Similar level of improvement was observed for the patient studies. **Conclusion:** A spatial-temporal reconstruction formalism has been established to fully take advantage of the coincidence information acquired in the 4D acquisition process when reconstructing phase-resolved PET images**.** It allows us to obtain the statistically optimal 4D solution and substantially improved SNRs in 4D PET.

TH-D-330A-08

A New Arterial Input Free Method of Deconvolution in Functional CT

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Purpose: In functional CT (fCT), the arterial input function (AIF) and tissue curve are measured and used for calculating the functional parameters by deconvolution**.** A new method of deconvolution without the requirement of AIF is presented. **Method and Materials:** The AIF is determined by the injection profile (IF) and the dispersion due to the patient's physiology (i.e**.** "patient function", PF)**.** Eight patients with cervix carcinoma participated in a fCT study, in which X-ray contrast of 1.5ml/kg was injected at 4ml/sec**.** At the same time, a cine CT set was performed at a fixed slice at 1 rotation/sec for 120 sec**.** The AIFs are obtained from the CT scans and the PFs were determined by deconvolution of IF from AIF**.** The characteristics of PF were quantified and correlated with the patients' weight**.** The proposed method incorporates IF and PF into the deconvolution for the determination of functional parameters, as IF is known while PF can be partially determined in a population of patients**.** The method makes use of the strong correlation between PF and weight as constraint for deconvolution**.** The adiabatic tissue homogeneity model was examined**.** Functional parameters calculated with the conventional and new approach were compared. **Results:** The correlation coefficients of the maximum amplitude, peak-to-peak time, and amplitudes at 80 and 100 sec of PE, when correlated with patients' weight, were found to be -0.84, 0.45, -0.97 and -0.98 respectively**.** The spreads of the differences in blood flow, mean transit time, extraction fraction, and extravascular volume between the two methods were 2.83, 3.3, 6.29, and 6.45 % respectively**.** The mean differences of functional parameters between these two methods were <1 % except for extraction fraction (7 %). **Conclusion:** This study showed the feasibility to extract the patient function and incorporating it in deconvolution for fCT without the requirement of AIF.

TH-D-330A-09

Factor of Ten Dose Reduction in CT Perfusion Imaging

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Purpose: To reduce by a factor of ten the patient dose in contrast enhanced CT Neuro Perfusion protocols while maintaining SNR and physiologic information relative to standard full dose CT Neuro Perfusion protocols. **Method and Materials:** Our group's newly developed undersampling algorithm for contrast enhanced MRI, HighlY constrained back Projection (HYPR), is applied to a contrast enhanced CT Neuro Perfusion protocol. By using temporally redundant information in the time series, a reduction in the number of required projection angles for each time frame is possible. The time series data is acquired using interleaved and equally spaced projections. A composite image consisting of projection information from either the entire time series or a limited number of time frames is first constructed by the standard filtered back projection technique. Next, a HYPR time frame is reconstructed by multiplying the composite image by backprojections for each projection angle in the time frame after normalizing them by the corresponding projection from the composite image. **Results:** HYPR time frames with similar SNR to fully sampled images and containing equivalent physiologic information for the creation of perfusion parameter maps have been obtained. The simulated reduction in the number of projection angles for the studies completed would result in a reduction in dose by a factor of 10. Computed parametric maps of CBV, CBF, and MTT are qualitatively similar to that of full dose maps, and arterial and venous input functions show excellent agreement with full dose input functions. **Conclusion:** The application of HighlY constrained back Projection (HYPR) to contrast enhanced CT Neuro Perfusion protocols allows a potential reduction by an order of magnitude to the delivered patient dose while maintaining SNR and physiologic information in the form of CBV, CBF, and MTT maps and arterial, venous and tissue input functions.

Imaging Symposium Room 330 D

Biomedical Imaging Research Opportunities Workshops (BIROW): A Guiding Consortium of Imaging Societies with NIH Support

TH-D-330D-01

BIROW - Biomedical Imaging Research Opportunities Workshop: Intersociety Project to Accelerate Biomedical Imaging Discovery and Application

G Fullerton*[1], J Bourland [2], C Pelizzari [3], C Ling [4], D Jaffray [5], W Eckelman [6], B Patt [7], W Hendee [8], J Mulvaney [9], T Mackie [10], A Fenster [11], P Nagy [12], M McNitt-Gray [13], H Chan [14], (1) UT Health Sciences Center, San Antonio, TX, (2) Wake Forest Univ, Winston Salem, NC, (3) Univ Chicago, Chicago, IL, (4) Mem Sloan-Kettering Cancer Ctr, New York, NY, (5) Princess Margaret Hospital, Toronto, ON, CA, (6) Molecular Tracer, LLC, Bethesda, MD, (7) Gamma Medica, Inc., Northridge, CA, (8) Medical College of Wisconsin, Milwaukee, WI, (9) Agfa, Orlando, FL, (10) University of Wisconsin, Madison, WI, (11) Robarts Research Institute, London, ON, CA, (12) University of Maryland Medical Center, Baltimore, MD (13) UCLA School of Medicine, Los Angeles, CA, (14) Univ Michigan, Ann Arbor, MI

The Biomedical Imaging Research Opportunities Workshops (BIROW) held over the past 4 years examined the leading edge of research opportunities in biomedical imaging, to recommend strategies to advance imaging research and thereby improve imaging applications in preventive medicine, medical diagnosis and treatment**.** Funded through grants from the National Institute of Biomedical Imaging and Bioengineering (NIBIB) and the Whitaker Foundation, and held each spring in Bethesda MD, the BIROW workshops were sponsored by 5 organizations**:** the American Association of Physicists in Medicine, Radiological Society of North America, Biomedical Engineering Society, Academy for Radiology Research, and the American Institute of Medical and Biological Engineers**.**

This session introduces the purpose and accomplishments of BIROW and plans for its future, followed by discussions by several leading researchers on topics of substantial current interest in biomedical imaging research**:**

Image-Guided Therapy (Drs. Bourland, Pelizzari, Ling and Jaffray); Small Animal Imaging Systems (Drs. Fullerton, Eckelman and Patt); Medical Imaging Technology: From Concept to Clinic (Drs. Hendee, Mulvaney, Mackie and Fenster); and Informatics and Computerized Image Analysis (Drs. Nagy, McNitt-Gray and Chan). Participants in this session will gain insight into the types of research challenges and opportunities present in BIROW workshops through the presentation of these examples.

1:30 -1:50
Introduction Session: Purpose of BIROW
1:50 - 3:20
Image-Guided Therapy
Small Animal Imaging Systems
4:00 - 5:30
Medical Imaging Technology: From Concept to Clinic
Informatics and Computerized Image Analysis

Joint Imaging/Therapy Valencia B
Scientific Session
Kilovolt and Megavolt Imaging for Therapy Guidance

TH-D-ValB-01

Correction of Couch Artifacts in KV Cone-Beam CT From An On-Board Imaging System

I Ali, D Lovelock, S Kriminski, J Chang, H Amols, I Ali*, Memorial Sloan-Kettering Cancer Ctr, New York, NY

Purpose: To evaluate artifacts caused by treatment couch attenuation on 3D image reconstruction for a new kV on-board-imager (OBI) and cone beam CT (CBCT) system and to develop an algorithm that filters couch effects from two-dimensional radiographic projections prior to inputting to the 3D reconstruction algorithm. **Material and methods:** A standard quality assurance phantom was scanned in air and on couch top using both full and half fan cone-beam scanning modes with and without bowtie filter combination. A spatial domain filter algorithm was developed to remove couch attenuation from each radiographic projection. This filter is based on a pixel-by-pixel subtraction technique of radiographic projections of cone-beam scans of the couch from the corresponding radiographic projections of scans with phantom on top of the couch. The net couch-filtered radiographic projections were used to reconstruct CT images. **Results:** CT numbers for scans of the phantom on couch top are less uniform than for scans of the phantom in air. The couch artifacts vary the linearity of the CT numbers by 5-15%, depending on the density of the material. Noise of the scans with phantom on couch top (3.5%) is higher than that with phantom in air (1.5%). The increased noise hinders the ability of the CBCT system to resolve low-contrast regions when the couch is present. Pre-reconstruction processing of the couch suppresses noise (< 1.5%) improves uniformity by a factor of 2 and removes ring and streak artifacts in the couch-filtered reconstructed CBCT images. **Conclusion:** The treatment couch produces streaking artifacts, enhances noise, and causes drifting of CT numbers in the reconstructed OBI CBCT images. The developed couch pre-processing algorithm suppresses noise, improves CT number uniformity by a factor of 2 and removes ring and streak artifacts in the couch-filtered reconstructed CBCT images.

Conflict of Interest: Supported by NCI Grant P01-CA59017

TH-D-ValB-02

Skin and Body Dose Measurements for Varian Cone-Beam CT (CBCT) During IMRT for Prostate Cancer

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Purpose: With the increased use of CBCT for daily patient setup, kV dose delivered to patient should be investigated. This study is to measure skin and body dose from Varian daily CBCT for prostate patients. Methods and Materials: CBCT scans were acquired in half-fan and pulsed-fluoro mode with a half bow-tie mounted. A technical setting of 125kV, 80mA and 25ms was used. Skin and body doses were first measured for a Rando pelvic and an IMRT QA phantom, set centrally, with TLD and a cylindrical chamber. Then skin dose for 7 prostate patients undergoing daily CBCT was measured. To avoid the ring artifacts centered at prostate, the treatment couch was dropped 3cm from patient's tattoo. TLD capsules were placed on patient's skin at 3 sites: AP, Lt Lat and Rt Lat. Phantom measurement was also made for this setup. The absorbed dose was determined by the air-kerma-based calibration method recommended by TG61. Results: For phantoms set centrally, measured skin dose was ~6 cGy, ~5.6 cGy, ~3.7cGy at AP, Lt Lat, and Rt Lat, respectively. Body dose at the center was ~3-4 cGy. With table dropping (TD), only AP skin dose was increased ~12%. Patient AP skin dose varied with separation, ranging 4–6 cGy for thicker patients (AP 23 – 33 cm) and 6 – 8 cGy for thinner patients. Minimum changes were observed on lateral dose for patients with different size. Lt Lat skin (4cGy) and bone (9cGy) doses were higher than Rt Lat skin (3cGy) and bone dose (6cGy) Conclusions: Daily CBCT provides better patient setup but it increases skin and body dose. The dose can range from 120 – 330 cGy for skin and 120 – 380 cGy for body during the 42 daily fractions delivered for IMRT prostate patients.

TH-D-ValB-03

Unified Algorithm for KV and MV Scatter and Beam-Hardening Correction Using the Convolution-Superposition Method

J Maltz*, B Gangadharan, D Hristov, A Paidi, S Bose and A Bani-Hashemi, Siemens Medical Solutions USA, Concord, CA

Purpose: Quantitative cone beam CT (CBCT) is essential for advanced radiation oncology (RO) applications such as portal image-based 3D dose reconstruction. Quantitative CT requires accurate modeling of scatter, beam-hardening and detector response. Scatter correction methods are typically semi-empirical in nature and are designed to reduce visible artifacts while incurring low computational cost. In contrast, Monte Carlo (MC) methods are accurate but impractically slow. Convolution-superposition (CS) scatter models offer a good balance between accuracy and computational complexity. We show how CS can be employed to implement a unified correction method that enables quantitative kV and MV imaging. **Method and Materials:** (1) We perform detailed MC modeling of the kV and MV cone beam imaging systems. (2) Using MC, we generate calibration data that map intensities recorded on the flat panel imagers to water-equivalent thicknesses (WETs). (3) The MC models are used to generate pencil beam kernels for water cylinders of varying thickness. (4) Scattergrams are generated from acquired projection images via the CS method using these kernels indexed by the WET at each pixel. (5) Scattergrams are iteratively refined using a multiplicative correction formula that ensures that the estimated primary image remains non-negative even when scatter-to-primary ratios are very high. (6) The FDK reconstruction algorithm is applied directly to the thickness maps corresponding to the estimated primary images. **Results:** The algorithm is able to reduce maximum non-uniformity in the reconstruction of a 16cm cylindrical homogeneous tissue equivalent phantom from 11.7% to 1.5%. When applied to a challenging 35cm x 22.5cm oblong water phantom, a non-uniformity reduction in from 36% to 2.5% is achieved. A dataset of 200 1024x1024 projections can be processed in 25 seconds. Conclusions: CS methods can be used at both kV and MV energies to enable reconstruction of quantitative CBCT images. **Conflict of Interest:** Supported by Siemens.

TH-D-ValB-04

Patient Alignment Using Megavoltage Cone-Beam CT

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Purpose: The growing use of conformal radiotherapy techniques has motivated the development of in-room imaging systems capable of producing a patient 3D image that can be compared with the planning CT. We report on the Megavoltage Cone-Beam CT (MVCBCT) positioning accuracy and its first clinical use for alignment of head and neck patients. **Method and Materials:** Using a standard treatment unit equipped with a flat panel detector, we compared a 2D setup technique using digitally reconstructed radiographs and portal images with a 3D setup technique using a diagnostic CT and MVCBCT. A gold seed placed at isocenter was imaged over time to measure the MVCBCT absolute positioning accuracy and stability. A Rando head phantom was imaged at 23 different locations in the treatment field to measure the capability of both setup techniques to

determine shifts. A total of 18 MVCBCTs and corresponding pairs of orthogonal portal images were acquired on 8 patients undergoing treatment for head and neck cancers. **Results:** The absolute positioning accuracy of MVCBCT was better than 1.5 mm over several weeks. The mean and standard deviations of the differences between applied and measured shifts on Rando were (0.0±0.5) and (0.0±0.9) mm for MVCBCT and portal imaging respectively. For patient images, bony anatomy and soft-tissue was visualized on MVCBCT while only bony structures could be used for alignment on portal images. The shift measurements made with the two methods were within 2 mm of each other in 68% of cases. However, differences as large as 4 mm were observed. **Conclusion:** The phantom measurements indicate that portal imaging and MVCBCT have the potential to verify patient shifts with sub-millimeter precision. MVCBCT performed on patients showed translation shifts, rotations and anatomy deformations not always appreciated using portal imaging. **Conflict of Interest:** Research sponsored by Siemens OCS.

TH-D-ValB-05

Evaluation of Image Quality in Megavoltage Digital Tomosynthesis

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Purpose: We report on the characteristics of Megavoltage Cone Beam Digital Tomosynthesis (MVCB DTS) and its potential clinical application for imaging of pulmonary lesions. **Method and Materials:** MVCB CT refers to the reconstruction of a 3D image from a set of 2D projections, acquired using a medical linear accelerator equipped with an electronic portal imaging device (EPID). A typical MVCB CT scan is acquired over a 200 degrees arc. In the case of MVCB DTS, the angular range is limited to reduce the acquisition time. This limited angular range affects the image quality of the reconstructed tomograms. To study the image quality as a function of the angular range, phantom measurements were performed and data from a head and neck patient were analyzed. The image quality was analyzed in terms of effective slice thickness, shape distortion and contrast sensitivity. MVCB DTS of the lung was performed on patients, with localized and diffuse lesions. **Results:** The image quality and the capability to distinguish overlaid structures decreases with decreasing angular range: a 20 degrees arc DTS results in a slice thickness of 2.7cm (vs. 1mm), a ratio of the vertical to lateral diameter of a sphere of 0.15, and a reduced contrast sensitivity. The acquisition is faster than MVCB CT. It takes 5-10 seconds for arcs of 20-40 degrees, compared to 45 seconds for a 200 degrees arc. In lung images, the faster acquisition results in a reduced blur due to the respiratory motion. **Conclusion:** This study indicates some potential advantages of DTS for imaging lung patients in the treatment position. Compared with EPID, DTS provides 3D information and better soft tissue contrast. Compared with CBCT, DTS allows shorter acquisition times, compatible with breath holding.

Conflict of Interest: Research sponsored by Siemens OCS.

TH-D-ValB-06

Four-Dimensional MVCT Reconstruction Using Temporal Re-Binning

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Purpose: To reconstruct 4D-CT images using temporal re-binning of sinogram projections from a slow-CT scan of an object simulating respiratory motion. Methods and Materials: A slow-CT scan of a battery-powered motion phantom was taken using a helical tomotherapy machine. The motion phantom consisted of an elliptical disk with maximum diameter of 8.5-cm, mounted on a spindle offset from the center of the major axis of the disk. The rotating spindle created a wobble in the disk's motion that simulated respiration. Atop the motion phantom, a CT resolution plug rested on a platform that moved vertically 1.5-cm with a rotational period of 7 seconds. The plug was made of water equivalent material with seven holes of with diameters ranging from 2.00-mm to 0.5-mm. The vertical motion of the resolution plug was measured using a real-time respiratory gating system. The CT image sinogram obtained from the machine detector was reconstructed using a program from the manufacturer of the helical tomotherapy machine. A program was written to shuffle sinogram projections, producing reconstructed slices over a range of movement (bin). The sorted slices were compared to the original CT images of the resolution plug. Not every bin contained a full gantry rotation of projections, and missing projections were replaced. Three replacement methods were used to obtain the best possible slice reconstructions. **Results:** The reconstructed CT slices showed improvement in resolution over the CT image of the plug in motion over the entire range of bins examined. Smaller bins with fewer missing projections had similar resolution to the static CT image of the plug. It was shown that bin enlargement showed the finest resolution of the projection replacement methods examined. **Conclusions:** Temporal re-binning of slow-CT sinogram projections can reduce motion artifacts and improve image resolution, but methods must be devised to accommodate for missing data.

TH-D-ValB-07

Development of a Novel High Quantum Efficiency Flat Panel Detector for Megavoltage Cone Beam CT/DT: Construction and Evaluation of a Prototype Single-Row Detector

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Purpose: Most electronic portal imaging devices (EPIDs) developed so far have low x-ray absorption, *i.e.*, low quantum efficiency (QE) of 2-4% for megavoltage x rays. A significant increase of QE is desirable for applications such as megavoltage cone-beam CT (MV-CBCT) and digital tomosynthesis (MV-CBDT). Our overall goal is to develop a new generation of area detectors for MV-CBCT/DT, with a QE an order of magnitude higher than that of current EPIDs and yet an equivalent spatial resolution. To this end, a novel direct-conversion design of such a high QE detector was introduced recently [Pang and Rowlands, Med. Phys. 31, 3004 (2004)]. The purpose of this work is to construct and evaluate a prototype single-row detector. **Method and Materials:** A prototype single-row detector was constructed based on the novel design. It consists of a single custom-made printed circuit board (with microsize cavities, charge collection electrodes and microstrip spacers) sandwiched between two identical tungsten plates. The detector array has 128 pixels each with dimensions of 0.45mm (width)×0.6mm (length)×22mm (height). The detector array was placed inside a sealed vessel filled with Xe gas (ionization medium) and then connected to a data acquisition board (XDAS, Electron Tubes Ltd.) for readout. Some fundamental imaging properties including QE, noise power spectrum (NPS) and detective quantum efficiency (DQE) were measured with a 6MV beam. **Results:** Phantom images were obtained using a dose as low as one Linac pulse. The QE of the prototype is ~ 66% at 6MV. The DQE at zero frequency is more than an order of magnitude higher than that of current EPIDs. **Conclusion:** This work demonstrated the feasibility of our novel design for a high QE MV detector. Construction and evaluation of a prototype flat-panel area detector is in progress.

Conflict of Interest: Supported by the DOD Prostate Cancer Research Program (DAMD17-04-1-0276).

TH-D-ValB-08

Commissioning of a KV Image-Guided System

D Moseley*[1, 2], E White[1], T Purdie[1], J Bissonnette[1, 2], M Sharpe[1, 2], K Brock[1, 2], J Siewerdsen[2], D Jaffray[1, 2], (1) Princess Margaret Hospital, Toronto, ON, CA, (2) University of Toronto, ON, CA

Purpose: Linac-based kilo-voltage x-ray systems for image-guidance have been widely adopted in radiation therapy. Over recent months, six cone-beam CT enabled linacs have been installed and commissioned in our clinic. In the era of image-guidance, a reference image of the patient anatomy and the treatment plan must be delivered to the unit for matching. This requires coordination of the simulation, planning and delivery systems. This work describes the commissioning and integration process for kilo-voltage x-ray image-guidance systems in the modern radiotherapy clinic. **Method and Materials:** Accuracy and reproducibility of the kV source was measured using the RTI Barracuda diagnostic x-ray meter. Image quality of the cone-beam CT acquisition system was assessed using the CatPhan 500 multi-slice CT image quality phantom. Metrics here include spatial resolution, uniformity, CT# accuracy and linearity as well as scale, orientation and slice thickness. Geometric coincidence of the imaging and treatment iso-centers was verified using a steel BB localized to the MV radiation iso-center using a Winston-Lutz technique. A custom-

made anthropomorphic torso phantom was CT simulated and planned in four orientations (head first supine, head first prone, feet first supine and feet first prone) and exported to each linac for image-guided setup correction and "treatment". This tested the DICOM connectivity, orientation, scale, structure sets and isocenter of the imported reference images as well as magnitude and direction of couch corrections. **Results:** The average absolute error after correction across all orientations and all platforms was (0.8±0.7, 0.6±0.7, 1.0±0.7) [mm±1S.D.] (L/R, S/I, A/P). **Conclusion:** A commissioning process for linacs with kilo-voltage imaging was described. Image-guided radiotherapy increases precision and accuracy of the delivered treatment but it also increases the demand for integration and coordination of other systems in the modern clinic. C**onflict of Interest:** This work is sponsored by the Elekta Synergy Research Consortium.

Professional Course Room 230A
Economics Refresher

TH-D-230A-01
Economics Refresher Course: How Medical Physics Services Are Reimbursed

J Hevezi*, G White*, (1) South Texas Oncology & Hematology, San Antonio, TX, (2)Colorado Associates in Medical Phys, Colorado Springs, CO

Medical physics services in medicine are reimbursed through the Current Procedural Terminology (CPT) Codes published by the American Medical Association in an annual publication. Although CPT codes for medical physics services appear explicitly in the radiation oncology series of CPT codes (77XXX), diagnostic radiological physicists may use several of these codes to cover patient specific work they may be called on to perform. This refresher course will trace the advent of the Centers for Medicare and Medicaid Services (CMS) relative value system for reimbursement for medical services and explain in detail how the complex system operates for current and new technology codes. Payments differ in various settings such as hospital, free-standing center and ambulatory surgical center and these differences will be traced for each site of service.
Additionally, private health insurance carrier are not required to follow the precepts of the CPT formalism and these reimbursement entities will be described in their methodology of reimbursement for these services. Finally, ancillary publications that impinge on these reimbursement rules (eg. Correct Coding Initiative, CCI) will be referenced. Coding compliance guides such as those published by ASTRO and ACR will form the basis for this economics refresher course.

Therapy Continuing Education Course Room 224 A
CE: Quality Assurance for IMRT and IGRT

TH-D-224A-01
QA for Tomotherapy

W Tome*, H Jaradat, D Westerly, J Fenwick, N Orton, T Mackie, B Paliwal, University of Wisconsin, Madison, WI, University of Wisconsin - Madison, Madison, WI

Purpose: To describe the commissioning and quality assurance for helical tomotherapy machines. **Method and Materials:** Helical tomotherapy is a volumetric image guided, fully dynamic, IMRT delivery system. It was been developed at the University of Wisconsin and is now commercially manufactured as the 'Hi-Art'. At the core of this fully dynamic IMRT Delivery system lies a short gantry-mounted linac that is used both for treatment and per-treatment MVCT imaging. Aside from the primary collimator and the jaws, which set the width of the beam, it is also collimated by a binary multileaf collimator generating a fan beam of intensity-modulated radiation. Modulation varies with gantry angle. Hence, the Hi-Art allows for the acquisition of a helical pre-treatment MVCT scan that is used for online image guidance and allows for precise interfraction positioning of the patient while in the actual treatment position just prior to the start of treatment. Due to its unique design the Hi-Art system, allows highly conformal dose-distributions to be delivered to patients in a helical fashion. Patients are treated lying on a couch that is translated through the bore of the machine as the gantry rotates, therefore the Hi-Art is the therapy equivalent of helical CT. Since this approach to therapy is fully dynamic it requires synchrony of gantry rotation, couch translation, linac pulsing and the opening and closing of the leaves of the binary multileaf collimator used for beam modulation. **Results:** Over the course of the clinical implementation of the HiArt we have developed a quality assurance (QA) system that covers machine specific QA. The machine specific QA system is similar to that recommended for conventional linear accelerator QA by AAPM Task Group 40; however since the Hi-Art design and operation differs from that of conventional medical linear accelerators, the tomotherapy QA system contains also novel components, such as QA checks for synchrony of gantry rotation, couch translation, linac pulsing and the opening and closing of the leaves of the binary multileaf collimator. **Conclusion:** In the first part of the presentation the design and dosimetric characteristics of Hi-Art machines are summarized and the QA system is described along with experimental details of its implementation, while in the second part the pre-treatment patient-specific delivery QA for helical tomotherapy is discussed.

Learning Objectives:
1. The audience will understand the rationale for the proposed machine specific QA for Tomotherapy machines and how to carry out the various tests in a systematic and controlled fashion
2. The rationale for the proposed patient specific pre-treatment QA and how to carry it out in a systematic and controlled fashion will be understood.

TH-D-224A-02
Physics Aspects of Clinical Trials: From the Basics to IMRT and IGRT

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Medical physicists play an important role in the success of clinical trials involving radiation therapy. An understanding of how these clinical trials work is necessary and expected of the physicist involved with these treatments. AAPM Report #86, Quality Assurance for Clinical Trials: A Primer for Physicists, provides background information to physicists participating in clinical trials and will be reviewed.

The second part of the presentation introduces a new initiative within the AAPM that will affect how clinical trials are conducted. The goal of AAPM Task Group 113 is to provide guidance to physicists and others involved in clinical trials on methods to improve the consistency and quality of data generated for trials involving external beam radiotherapy. This presentation will discuss factors that impact data quality for the entire treatment planning and delivery process with an emphasis on advanced technologies such as IMRT and IGRT. The scope of Task Group 113 includes image acquisition for volume definition, treatment planning systems, patient localization, treatment guidance and delivery, and credentialing for clinical trials.

Educational Objectives:
1. To review the primer on QA for Clinical Trials
2. To describe the goals of TG#113 Physics Practice Standards for Clinical Trials
3. To highlight factors that directly impact clinical trials that involve IMRT and IGRT

Therapy Scientific Session Room 224 C
Clinical Measurements and Quality Assurance

TH-D-224C-01
A Quality Assurance Procedure to Monitor Mechanical Stability and Image Quality of An On-Board KV Cone-Beam CT Imager

I Ali*, D Lovelock, T LoSasso, H Amols, Memorial Sloan-Kettering Cancer Ctr, New York, NY

Purpose: To develop Quality Assurance (QA) procedures that monitor mechanical stability and image quality performance of a new kV on-board-

imager (OBI) and cone beam CT (CBCT) system. **Material and Methods:** QA of mechanical stability includes measurements of the OBI kV and Linac MV isocenters, shifts resulting from gantry rotation, translational of imager, flexing of support arms, and reproducibility of couch shifts. Image quality QA includes measurement of noise, CT number uniformity, linearity, spatial and contrast resolutions. **Results:** Our system has a systematic shift between kV and MV isocenters of ~1.4 mm. Translational motion of the OBI is accurate to ~0.9 mm and rotational motion to ~0.2 mm. Couch positioning accuracy has an error of ~0.9 mm longitudinally. CT numbers are less uniform than for conventional CT with full fan (without filter) CBCT scans producing better results than other modes (CT number uniformity ~2.5%). σ for CBCT is about 1% worse than for conventional CT and thus low-contrast level objects such as supra-and sub-slice targets with < 0.5% nominal contrast in the contrast resolution module are not resolved in CBCT. CBCT numbers agree with simulator CT within 3% in the range -1000 to +1000 for scans in air. High-contrast resolution of the OBI cone-beam CT is comparable to the conventional CT simulator. **Conclusions:** Systematic shifts of the OBI isocenter from radiation isocenter must be considered for patient setup and IGRT procedures using CBCT. Systematic isocenter shifts caused by rotational and translational motions of couch and gantry must also be corrected for to achieve sub-millimeter target localization accuracy. Image quality of kV cone-beam CT is inferior to conventional simulator CT in terms of uniformity, and low-contrast resolution, but has comparable CT number linearity and high-contrast resolution. **Conflict of Interest:** This work is supported by NCI Grant P01-CA59017

TH-D-224C-02

The State of Radiotherapy Physics Through The Eyes of a Quality Auditor

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Purpose: To assess the radiotherapy programs of institutions participating in NCI sponsored clinical trials and assist them to implement remedial actions. **Materials and Methods:** The Radiological Physics Center (RPC) has developed an extensive Quality Assurance (QA) program over the past 38 years. This program includes on-site dosimetry reviews where measurements on therapy machines are made, records are reviewed and personnel are interviewed. The program's remote audit tools include mailed dosimeters (TLD) to verify output calibration, comparison of dosimetry data with RPC "standard" data, evaluation of benchmark and patient calculations to verify the treatment planning algorithms, review of institution's QA procedures and records, and use of anthropomorphic phantoms to verify tumor dose delivery. The RPC assists institutions in finding the origins of discrepancies, and in resolving them. **Results:** The percent of institutions receiving dosimetry recommendations has been level at 70% for the past 5 years. The most frequent recommendations were for maintenance of an appropriate QA program, beam calibration, depth dose and wedge factors. Since TG-51 was published, the number of reference calibrations meeting the RPC's ±3% criterion has decreased. The TLD program shows that only ~3% of the beams are outside our ±5%/±5mm criteria, but these discrepancies are distributed over nearly 15% of the institutions. There continues to be a 33% percent first time failure rate for the IMRT H&N anthropomorphic phantom. The other anthropomorphic phantoms, i.e. pelvic IMRT, lung stereotactic and liver stereotactic, have higher pass rates. **Conclusion:** Numerous dosimetry errors continue to exist and the RPC's QA program plays an important role in identifying and helping institutions resolve these errors to improve not only the quality of clinical trial patients' treatments, but also all patients treated at the participating institution.

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TH-D-224C-03

Integral Test Phantom For Dosimetric and Geometric Assurance of IG-IMRT

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Purpose: To develop a combined imaging and dosimetric phantom for the quality assurance (QA) of linear accelerators capable of cone-beam CT image-guided and intensity modulated radiotherapy (IG-IMRT). This integrated approach verifies image quality, registration, and delivery performance. **Method and Materials:** The prototype consisted of a cylindrical imaging phantom (CatPhan) combined with an array of 11 radiation diodes arranged in a plane, oriented perpendicular to the phantom axis. Single diode performance was assessed at 6 and 18 MV (profiles, depth-dose curves and angular dependence) with comparison to ion chamber. The detection of geometric and dosimetric errors in delivery was assessed using an IG-IMRT treatment (6 MV, 7 beams, 180 cGy, CBCT-guided) in which known displacements relative to isocenter were applied. The minimum detectable shift was determined by comparing the discrepancy between planned and measured doses to the dose measurement uncertainty under non-shifted conditions. **Results:** Diode profiles and depth dose curves agreed generally within ±1% with the chamber results. Angular dependence for the diode was low for axial beams (±1%) but increased to a maximum of 11% for out-of-plane irradiation. The normalized dose measurements obtained with the multi-diode phantom agreed well with the planning results. Displacements as small as 1 mm resulted in detectable deviation dose (8.2 cGy SD, n=11) relative to the uncertainty in dose measurements for non-shifted conditions (1.6 cGy SD, n=11). **Conclusion:** A phantom prototype was designed and constructed for comprehensive QA of image-guided radiotherapy in terms of image quality and dose delivery. The results allow us to set specifications for further development. We anticipate the system will permit the localization/detection of sub-millimeters errors in dose gradient placement. Future phantom designs will facilitate absolute dosimetry and investigate the use of additional diodes in different patterns. **Conflict of Interest:** Supported in part by Sun Nuclear Corporation and Elekta Inc.

TH-D-224C-04

Mechanical, Radiation and Imaging Isocenter Quantification On Four Varian On-Board Imager Clinacs

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Purpose: Varian has recently introduced the On-Board Imager (OBI) based image guided radiation therapy (IGRT). The OBI system comprises of a kV x-ray source and an amorphous silicon detector mounted on robotic arms perpendicular to the gantry. Our aim was to quantify and verify the coincidence of the mechanical, radiation and imaging isocenters for four OBI Clinacs (including one Trilogy linac) we recently purchased at our institution. **Method and Materials:** The mechanical isocenter (gantry, collimator and couch) was determined using the Radac 2100 device (Medtec). Once the exact mechanical isocenter of the linac was confirmed, the lasers were aligned precisely through the isocenter. The radiation isocenter was then measured using the classical star-shot technique as well as using the Winston Lutz technique. The Varian supplied isocenter cube device (with a ball in the center) was then positioned on the exact couch at the mechanical and radiation isocenter coincidence point. kV images were then taken at the four cardinal gantry angles 0, 90, 180 and 270 degrees to determine the imaging isocenter. **Results:** The coincidence between the mechanical, radiation and imaging isocenter are within 1 mm for all four Clinac's. The gantry and collimator mechanical isocenter was typically much less than 1 mm radius for the linacs (< 0.5 mm for the Trilogy). The radiation isocenter was also less than 1 mm radius for all the linacs. The imaging isocenter was less than 0.8 mm for all linacs. **Conclusion:** The added weight of the robotic arms, x-ray source and detector does not seem to have a negative effect on the mechanical and radiation isocenter of the Clinac's. The coincidence between the mechanical, radiation and imaging isocenter give confidence to shifts made using OBI based IGRT.

TH-D-224C-06

An Optimal MLC Quality Assurance Procedure Using EPID

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Purpose: IMRT QA is extremely time consuming and labor intensive, while IMRT delivery is complex. The purpose of this work is to develop an automated and quantitative IMRT QA process utilizing an EPID. One of the aspects of this is testing of MLC leaf position accuracy. The Memorial-Sloan-Kettering strip test was modified to provide an automated EPID-based process.

Method and Materials: To provide a baseline fluence map, Kodak XV film was irradiated to obtain an open field 2D beam profile, which was fitted with a Gaussian and used in the image correction routine. We used a strip test consisting of seven adjacent segments with an intentional gap of nominally 0.5 mm. The gap was intentionally varied for the positions located at regularly placed hexagonal regions in order to create a set of calibration curves. A fitting technique using a Lorentzian type function was developed to determine the dose-peak-height, dose-peak-position and FWHM. **Results:** The standard deviation of dose-peak-height at each abutment for traditional Memorial-Sloan-Kettering pattern was of the same order of magnitude as that of the average over the entire image. In contrast, in our pattern a difference of an order of magnitude was observed, which indicated the reducing of cross-talk effect from adjacent leaves. The leaf positioning error can be identified by using standard calibration curves of dose-peak-height vs. gap. The coordinate of dose-peak-position is found to be an extremely sensitive indicator of leaf error with sub-pixel standard deviation. **Conclusions:** This procedure is able to identify MLC positional errors less than 0.5 mm by using a fitting technique and by reducing the cross-talk effect. **Conflict of Interest:** Research sponsored by Varian Corporation

TH-D-224C-07

Focal Source Size Measurement for Monte Carlo Simulations of Percentage Depth Doses in Very Small Photon Fields

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Purpose: To measure the focal spot of a 10-MV Clinac-18 linac for use in Monte Carlo (MC) calculation of percentage depth doses (PDDs) in a very small (1.5 mm diameter) field. Methods and Materials: A technique using a translational slit-assembly system was developed to measure the linac focal spot. The assembly consists of two lead blocks fastened together to produce a 300 μm wide slit. A small field diode was centered below the slit, reading radiation signals transmitted through the slit while the system (mounted at a distance of 65 cm from the target) was translated linearly across an open beam. The linear translation was achieved through a screw driving mechanism and the position of the slit was measured with a digital caliper. The source dimension was estimated from the FWHM of the Gaussian fit to scanned profiles corrected for background transmission signal. **Results:** Scans in various angular orientations perpendicular to the beam central axis show that the linac focal spot is elliptical with principal axes of (1.1 ± 0.1) mm and (2.1 ± 0.1) mm. Isodose distribution measured on the solid water phantom surface in a plane perpendicular to the beam central axis for the 1.5-mm diameter, 10 MV photon beam is also elliptical and oriented in accordance with the measured source shape. A circular Gaussian source model with a FWHM of 1.5 mm, approximating the measured focal spot, was used in the MC calculation of PDDs for the 1.5 mm beam. The MC-calculated PDDs agree within 2% with measured data. **Conclusions:** In contrast to standard radiotherapy fields, MC-calculated PDDs for very small fields show a strong dependence on source dimension. The good agreement between the measured and MC-calculated PDDs for the 1.5 mm diameter 10 MV beam validates the MC simulation technique using appropriate focal source size.

TH-D-224C-08

Dose Variation Within Lung Tumor and in Its Fingerlike Extension as a Function of Incident Photon Angle

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Purpose: Report the dose variation within a lung tumor and its finger-like extension as a function of incident photon beam angle. **Method and Materials:** A phantom with 3-cm diameter acrylic sphere (tumor) inside a cork medium was designed so that the sphere could be rotated. TLDs were placed at various locations within the sphere and just outside the sphere. The outer TLDS simulated the tumor's finger like extension. Two 2.8cm thick acrylic plates (chest wall) sandwiched the phantom. The TLDS were exposed to a 6 MV beam of 10x10 cm^2 with the sphere centered at isocenter (100 SAD). The field size was such that the dose at the periphery of the acrylic sphere was not influenced by the beam penumbra. The exposures were repeated at every 30^0 of the fingerlike extension with respect to the incident beam angle. The doses at the TLDs were also calculated using MCNPX Monte Carlo codes and CC convolution algorithm. **Results:** The measured and calculated doses were normalized to the dose at the center of the sphere. Then ratios of MC and convolution values to measured values were calculated and plotted as a histogram. The standard deviations for MC and convolution to TLD ratios were 3.5% and 1.1% respectively. The standard deviations of random error in TLD, MC and convolution methods were 2, 3 and 1.5% respectively. **Conclusions:** MC and CC convolution values agreed well with measured data. The data would be presented as function of incident beam angle. In addition, analysis of a PB algorithm and an 18 MV beam data would be presented.

TH-D-224C-09

Implementation of the Varian Eclipse System for Proton Therapy Treatment Planning

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Purpose: To configure and test a treatment planning system (TPS) (Varian, Palo Alto) for use with a passively-scattered proton therapy delivery system. **Methods and Materials:** Since the mechanical designs of the commercial beam delivery apparatus (Probeat, Hitachi Limited, Japan) had not yet been completed, measurements of the required data were not possible. Instead, we designed our own therapy system components using analytical methods. The MCNPX (Los Alamos National Laboratory) Monte Carlo (MC) code was used to simulate beam profiles. Separate codes were developed to create the initial proton sources, the absorbed dose and fluence tallies, and simple homogeneous water phantoms (see Zheng *et al.*, separate contribution). Up to 10^8 proton histories were tracked per simulation to achieve < 2% statistical uncertainties. Additional codes were developed to generate ancillary TPS configuration files, e.g., for the range modulator wheels, flattening filters, and variable range shifter. The MC beam characteristics such as penetration range were compared with values from independent one-dimensional analytical calculations. **Results:**
A complete set of configuration parameters and beam profiles were generated, including 832 dose and fluence profiles, in approximately four weeks (simulation time using 60 CPUs). With the simulated configuration data, the TPS has undergone extensive development and testing during the past year. Preliminary results indicate that the MC, TPS, and independent analytical calculations are in good agreement (< 4 mm differences in penetration range). **Conclusion:**
The results of this study demonstrate the practicality of MC models to calculate beam data for configuring a proton treatment planning system. Additional simulations with the manufacturer's preliminary equipment designs are now in progress. Validation tests of Eclipse in heterogeneous media are in progress (see Titt et al., separate contribution). Confirmatory measurements are planned. **Conflict of Interest:** This work was funded in part by a research grant from Varian.

TH-D-224C-10

Commissioning and QA of Cone Beam CT for Image Guided Radiation Therapy

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Purpose: To report the results of commissioning tests and the development of a quality assurance program for the commercial version (i.e., non-research model) Elekta Synergy Cone Beam CT (CBCT) system. Methods and Materials: Our institution was one of the first sites in the US to install a commercial version of the Elekta Synergy Cone Beam CT system. A commissioning procedure was developed consisting of six parts: (1) System safety, (2) Geometric accuracy (i.e., agreement of MV and kV beam isocenters), (3) Image quality, (4) Algorithm accuracy, (5) Dose to patient, and (6) Quality assurance procedures. **Results:** The system passed all safety tests and agreement of MV/kV isocenters was found to be within 1 mm. Using a precisely moved skull phantom, reconstruction and alignment algorithm was found to be accurate within 1mm and 1 degree in each dimension. For 12 measurement points spanning a 9x9x15cm^3 volume in a RANDO phantom, average agreement in x, y, and z coordinates was 0.010cm, -0.012cm, 0.022cm (SD: 0.021cm, 0.055cm, 0.021cm; Largest deviations: 0.06cm, 0.10cm, 0.05cm, respectively). Larger deviation for the y-component can be partially attributed to CT slice thickness of 1 mm along that direction. Dose to patient depends on machine settings and was found not to exceed 6.3cGy in the highest setting

used in our clinic (120kVp, 40mA, 40ms per frame, 360 degree scan, S20 field of view). A more typical dose for a full 360 degree scan is 4cGy. **Conclusions:** The procedures discussed in this presentation were applied to the Elekta Synergy CBCT system. They have been useful in identifying difficulties with the CBCT operation operation, including data transfer issues. System safety, geometric accuracy, and image quality checks are recommended to be performed on a monthly basis; algorithm accuracy and dose to patient checks are recommended to be performed annually.

Therapy Scientific Session Valencia A
Teletherapy Delivery III and Dose Calculation

TH-D-ValA-01

Preliminary Investigation of Multi-Pass Respiratory Gated Helical Tomotherapy (MRG-HT)

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Purpose: To investigate the feasibility of multi-pass respiratory gated helical tomotherapy (MRG-HT) technique by measuring the dosimetric degradation caused by target motion, and the resulting dosimetric improvements made by the MRG-HT technique **Method and Materials:** MRG-HT was simulated on the HT unit (Tomotherapy Inc.) by delivering a sequence of HT plans modified by blocking beam projections remaining outside the gating window (50 % duty cycle, end-expiration gating). After each plan delivery, the couch was reset and the succeeding plan was commenced at a different respiratory phase to allow the previously "blocked" beam projections to fall within the gating window. EDR2 film was placed inside a moving phantom (Modus Medical Devices Inc.), which was driven sinusoidally in the longitudinal direction. For each of the two scenarios with different experimental parameters, the resulting dose profiles along the axis of gantry rotation were obtained for a stationary target treated with the original plan, a moving target treated with the original plan, and a moving target treated with the MRG-HT technique. **Results:** In the first scenario, target motion led to underdosing 7.5 +/- 0.5 mm of the target and overdosing additional 2.0 +/- 0.5 mm of normal tissues. With the gating technique, these values were reduced to 4.5 +/- 0.5 mm and 1.0 +/- 0.5 mm, respectively. Further improvement could be achieved using a smaller gating window. In the second scenario, selected parameters caused significant dose modulations of 8.5 +/- 1.0 % inside the target, which was effectively eliminated by the MRG-HT technique. **Conclusion:** MRG-HT seems to be a very promising technique for gated HT. Its dosimetric improvement was demonstrated in the form of reducing target underdosing and dose modulations. In future, more sophisticated experiments will be made to simulate lung cancer treatment, including the effect of non-sinusoidal motion and lung inhomogeneity.

TH-D-ValA-02

Prepulse Effect and Maximum Energy of Protons Accelerated by High-Power Lasers

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Purpose: In recent years there has been an explosion of research work concerning the topic of charged ion acceleration using high-power lasers. The maximum particle energy and the shape of the distribution function are the two main parameters influencing the potential utilization of the new technology in radiation therapy. The energy spectrum depends on the quality of the laser beam as well as the geometric shape of the interaction target. Recent experiments have shown that it is possible to generate quasi-monoenergetic protons using a double target system. However, influence of the laser prepulse has not yet been fully quantified. The purpose of this study is to find how the laser prepulse changes the property of the target and under which conditions can one expect the highest proton energy. **Method and Materials:** A radiation-magnetodynamics code with inline atomic kinetic modeling was used to simulate interaction of the laser prepulse with initially cold double-layer target. The simulated target system consists of an aluminum substrate on which a thin layer of hydrogen is located. Different initial substrate thicknesses and laser contrast ratios were simulated to find an optimal interaction conditions. Results of hydrodynamic simulations were used as initial conditions for the simulation of the main pulse interaction with the altered target. **Results:** It is shown that interaction of the prepulse with the target leads to its partial ionization with subsequent formation of a shock wave. Propagating shock wave destroys initial configuration of matter in a substrate, greatly expanding it in laser's propagation direction. Results of simulations suggest that maximal proton energy is achieved using lasers with smallest contrasts, incident on targets of thicknesses 1-2 μm. **Conclusions:** Presence of laser prepulse impedes acceleration efficiency of protons. Minimizing the contrast ratio or shortening the duration of the prepulse should result in higher maximal proton energies.

TH-D-ValA-03

An Improved Lung Model, Incorporating Realistic Random Anatomical Features, for Monte Carlo-Based Dosimetry

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Purpose: To investigate the effects of incorporating a more physically-realistic lung model, preserving random anatomical features of the lung, on MC-based dose distributions. **Methods:** A random lung model was built based on morphological data. The model homogenizes the lung parenchyma with structures of "chunk" sizes less than 0.05 cm, and models all larger chunks (branches of the bronchial and vessel trees, up to ~1.5 cm) as randomly-positioned 2-D cylinders. The MC code PENELOPE was employed to calculate dose distributions in a water phantom containing a lung region, modeled by either a homogenized lung (as used in conventional planning) or the random lung model. Dose calculations used 6 and 18 MV photon beams with four different field sizes. **Results:** Depth dose curves in the random lung model illustrate significant perturbations when the structure size is comparable to the field size. For the 1x1 cm field size, large differences (up to 34% of D_{max}) exist in the largest structures due to the loss of CPE with small field size. For large field sizes (10x10 cm or higher), little difference is observed between the random and the homogeneous models. The additional attenuation of the large structures also results in a region of dose reduction behind the lung. **Conclusion:** A new random lung model reveals significant dose perturbations from the homogeneous model, and shows that the homogeneous model breaks down when the field size is comparable to the structure size. This work is of importance in IMRT planning, where beamlets are used, or in the treatment of small tumors, where small field sizes are used in the planning. This work suggests that in such cases, a more precise description of the lung geometry, e.g. a high resolution CT-based pixel-by-pixel density map, may be necessary for accurate dosimetry.

TH-D-ValA-04

Quantitative Evaluation of Cone Beam CT Data Used for Treatment Planning

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Purpose: To quantitatively evaluate the consistency of cone beam CT (CBCT) data and the deviation from helical CT if used for calculating dose to heterogeneous material. Methods and Materials: A Gammex RMI 467 tissue characterization phantom was used to generate CT numbers for both the Elekta XVI CBCT and the Picker 5000CT. For both devices, the RMI phantom was positioned using the manufacturer's recommendations. Hounsfield numbers (HU) were obtained using a default window and level and a ROI of 1cm diameter over the center of the rod (insert). The numbers were recorded and a HU vs. electron density correction curve was generated. For the cone beam portion, we used the Elekta XVI CBCT with M10 collimator and no filter. CBCT data, conventional CT data and correction curves were transferred to our CMS XIO treatment planning system. To verify the consistency of CBCT numbers, we added a 1cm of bolus to the phantom and repeated the procedure. A single field treatment plan was generated with heterogeneity and non heterogeneity corrections for CBCT and CT datasets, and for nonbolused and bolused geometries. The Gammex phantom tissue equivalent rods were modified to accept TLD for measurement verification. **Results:** Calculated doses for treatment plans generated without heterogeneity correction for data sets from CT and CBCT agreed within ~1%. CBCT numbers for the same insert differed with a small change in setup (ie. adding 1cm bolus). When heterogeneity correction was turned on, a difference of 14% was found between CT and CBCT nonbolused plans. TLD measured doses agreed with those from the

calculated CT set. **Conclusion:** Without heterogeneity correction, the dose calculation with CT and CBCT has excellent agreement suggesting a consistency in contour acquisition. One has to be extremely cautious in using CBCT data for heterogeneity corrections since significant error can occur.

TH-D-ValA-05

Effect of Measured Cone-Beam CT-Density Calibration On Dose Calculations

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Purpose: To characterize the CT-density conversion for a cone-beam CT (CBCT) system, and to evaluate the accuracy of dose calculation using CBCT images in head & neck (H&N) and abdominal sites. **Method and Materials:** A small (16 cm) and a large (32 cm) acrylic phantom with inserts of known electron densities were scanned on conventional CT and CBCT scanners. CBCT images were acquired using full and half fan (small phantom only), with and without bow-tie filter. CT-density conversion tables were measured for each combination. Head and pelvis phantoms, and H&N and prostate patients were imaged. IMRT treatment plans were designed based on conventional CT and transferred to CBCT after image registration (deformable registration for H&N patient). The CBCT dose distributions were then recalculated using the measured CT-density curves. **Results:** For the small phantom, minimal differences were found between CT and CBCT numbers. Different conditions (half/full fan, with/without bow-tie) resulted in maximum differences of approximately 100 HU. For the large phantom, differences between the CT numbers and CBCT numbers were greater than 350 HU at both low and high densities. For the H&N patient and the head phantom, dose distributions calculated on CT and CBCT differed by less than 2%. For the pelvis phantom and prostate patient, there were substantial differences in the dose distributions. In the worst case, using CBCT images and the measured CBCT-density conversion curve, the mean prostate dose was 14% higher than that calculated using the conventional CT. Due to artifacts in the CBCT, the differences in dose were larger using the CBCT-density curves than using the default CT-density curves. Using unit density for CBCT is a good approximation for pelvis dose calculation. **Conclusion:** Artifacts in CBCT images and CT-density conversion may lead to considerable errors in dose calculation using the large pelvis CBCT images.

TH-D-ValA-06

A Novel, Heterogeneity Inclusive, Pencil-Beam Based Algorithm to Improve Lung IMRT Using the Corvus Planning System

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Purpose: We investigate a new finite-size pencil-beam algorithm for calculating absorbed photon dose in heterogeneous media of arbitrarily varying density for inverse planning in CORVUS treatment planning system and evaluate its performance modeling heterogeneous systems and in optimization of an IMRT lung plan. **Method and Materials:** A new FSPB is developed by extending a phenomenological model (Med. Phys **26**:1893-1990, 1999) for the central-axis absorbed dose in therapeutic photon beams for heterogeneous media. The model's parameters are rescaled based on the density of the medium. A differential equation is introduced to model the interface build-up processes of CAX primary and scatter dose. Primary dose profiles are calculated using density-dependent kernel integration, interpolated in the FSPB axis direction and evaluated depending on the density at the point of interest. Scatter dose profiles are computed using scatter integration and evaluated locally. **Results:** The new heterogeneity inclusive FSPB was implemented in a development version of CORVUS. Original and new FSPB dose calculations were compared with Monte Carlo calculations performed using PEREGRINE. For a heterogeneous semi-slab phantom and for an IMRT lung plan, the dose distribution generated by the new FSPB agrees well with MC results, while the original one shows substantial discrepancies. IMRT plan optimizations were carried out using both original and new FSPB, and then a final dose calculation was performed using PEREGRINE. The plan calculated using the new FSPB shows better target conformality than the one computed using the original FSPB. **Conclusion:** The new FSPB possesses greatly improved accuracy as demonstrated in a variety of phantom and patient cases, both for dose calculation and IMRT optimization. FSPB best features were preserved with little extra computational overhead promising accurate and fast inverse planning and real-time dose sculpting and dose volume histogram manipulation.

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TH-D-ValA-07

Clinical Use of Monte Carlo in Proton Therapy: Pencil-Beam Algorithm Vs Monte Carlo for Proton Therapy of Skull-Base and Para-Spinal Tumors

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Introduction: Pencil beam algorithms rely on kernels to model proton range in density-scaled water equivalent material. Monte Carlo dose calculation methods are more accurate by design. This study addresses the issue of clinical significance of differences between a commercial pencil-beam algorithm and Monte Carlo dose calculation.
Skull-base or para-spinal tumors are challenging for dose calculations due to interfaces between high and low density areas in the irradiated volumes. In addition, for para-spinal cases, there are often metallic implants that not only distort the CT image but also affect the accuracy of dose calculations. **Methods:** Proton treatment planning is done at our institution by using FOCUS/XiO (CMS Inc.). To do full Monte Carlo based dose calculation the treatment head was modeled including a simulation of the modulator wheel rotation as well as aperture and compensator. The patient CT data information was converted into materials with explicit element composition and density. All secondary particles were tracked.
Treatment plans designed with the treatment planning program were re-calculated with the Monte Carlo code and compared by analyzing dose distributions and dose volume histograms. **Results:** In general, we found good agreement. Small differences are in part due to the difference between dose to medium and dose to water. Significant differences were found in and near air cavities as well as in areas affected by high density implants.**Conclusion:** For some tumors in the head and neck region and near the spine, Monte Carlo based dose calculation shows significant differences compared to pencil-beam algorithms. Consequently, at our institution, a sub-set of the patient population receives Monte Carlo dose calculation to assist in treatment planning.

TH-D-ValA-08

Experimental Evaluation of the Accuracy of Contralateral Lung Dose Calculations for IMRT Plans

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Purpose: To experimentally determine the accuracy of contralateral lung dose calculated by Eclipse for mesothelioma IMRT plans. **Materials and Methods:** Two planning techniques were used to create 9 mesothelioma IMRT plans in Eclipse, which were then applied to a Rando torso phantom. Group A consisted of 5 plans with 160° of the contralateral side free from entrance beams while the 4 Group B plans had 80°-90° free. MOSFETs were placed at 10 coplanar points within the contralateral lung of the phantom, and doses measured for each field for each plan. These were compared with doses calculated using the pencil beam algorithm (modified Batho) in Eclipse. Two controls (ipsilateral AP/PA and 40x40cm AP/PA) were evaluated. **Results:** The 40x40cm AP/PA control plan showed good agreement between Eclipse and experimental results with the difference being 1.04% +/- 3.62% (1 stdev), while the ipsilateral only AP/PA plan showed a disagreement of -33.3% +/- 6.9% (Eclipse was cold compared with measurements) suggesting poor scatter modeling. The overall average difference between measured and calculated daily doses of Group A and B plans was -21.1% +/- 15.7% (-6.98cGy +/- 5.2cGy) and –9.8% +/- 29% (-6.58cGy +/- 19.5cGy), respectively. The differences were dependent on whether the points were in or out of individual fields. The average difference for points in field for Group A and B plans were –5.5% +/- 23.4% (-1.169 +/- 4.99cGy) and +3.04% +/- 37.9% (1.57 +/- 19.6cGy), respectively. This increased to –49.2% +/- 10.9% (-5.8 +/- 1.28cGy) and –41% +/- 14.9% (-8.66 +/- 3.12 cGy), respectively, for points outside the field. **Conclusions:** Eclipse adequately models lung dose in field, but

underestimates scatter dose out of field by up to 50%. This should be considered when evaluating contralateral lung DVH's, especially when attempts are made to use IMRT to lower mean lung dose.

TH-D-ValA-09

An Objective Approach to Establishing Tolerances On Photon Beam Modeling Using the Equivalent Uniform Dose

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Purpose: To perturb a photon beam model in a controlled manner and to examine the consequences for the Equivalent Uniform Doses (EUD) of the target and organs at risk in external beam radiation therapy of the prostate. **Method and Materials:** We have developed seven similar but different therapy beam models in the Pinnacle® Treatment Planning System. One model generates beam data close to the golden data provided by Varian® and serves as the reference model for this study. The six other models are modifications of the reference model designed to result in controlled deviations of a particular region of the dose profiles (descending depth dose, build-up, horns, tail, penumbra and field width). We have analyzed the consequences of planning with these perturbed models on the quality of 4 prostate treatment plans in terms of the EUDs of the PTV, rectum and bladder in comparison with the reference model. Monitor units were kept constant for all plans. **Results:** to maintain a change in the EUD to the prostate, bladder or rectum of less than 2%, tolerances on the various regions of the dose profiles are as follows: descending depth dose 2%; horns 3%; field width ±1mm. Deviations in the build-up region and tail of ±10% and ±5% respectively did not change the EUDs of any structure by more than 2%. **Conclusion:** Currently accepted tolerances on photon beam modeling are broadly internally consistent in so far as they result in similar effects on plan dosimetry, at least for 4 field conformal prostate treatments.

Workshop — Room 230 C

Mammography QA Workshop - II

TH-D-230C-01

Mammography QA Workshop I and II

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Purpose: to explore the impact of DR mammography on the practice of medical physics. Historical and new methods for providing scheduled and unscheduled mammography services for facilities using DR mammography will be presented. **Method and Materials:** clinical medical physics services provided for DR mammography facilities from various manufacturers will be presented. Quality control activities approved by the FDA for each individual manufacturer will be compared. The status of a proposed "Alternative Standard" to allow for a more uniform approach to medical physics mammography services will be reviewed. Case studies will be presented demonstrating methods and cost considerations for providing medical physics services under the "minimum standard" (prescribed by MQSA regulations) and "best practices" model. **Results:** Medical physics services provided in the "minimum standard" and "best practices" model have implications for the quality and cost of mammography services. **Conclusion:** Medical physics services may be provided in a professional and valuable manner, using combinations of the minimum standard of practice and the "best practices" model. The professional medical should consider multiple parameters when determining the appropriate model under which to deliver services.

Imaging Scientific Session — Room 330 A

Cone-Beam CT

TH-E-330A-01

Computational Evaluation of Breast Geometry From Breast CT

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Purpose: Estimation of breast skin thickness and breast shape using a radial-geometry segmentation algorithm on breast CT images. **Method and Materials:** Forty-two breast image data sets were obtained from a prototype breast CT scanner, and were used to evaluate breast skin thickness and effective diameter. Patients were imaged at 80-kVp using x-ray tube currents (0.7 – 7.6 mA) depending on the patient's breast size. For each coronal breast image, the breast silhouette was segmented using a threshold value computed by a histogram-based iterative algorithm. Breast area was also computed from the thresholded coronal images. A 360-degree radial scan, originating at the center of mass of each breast CT image and continuing to the image edge, produced a radial profile of breast tissue intensity as a function of angle. A derivative filter was used to identify the inner and outer breast skin layers. In order to accurately estimate breast skin thickness, a tangent-finding algorithm was developed to correct the thickness measurement in non-circular breast geometries. A standard-deviation-based iterative algorithm was also implemented to reduce noise in the skin thickness estimation. **Results:** Among 42 patients, breast skin thickness was determined to be between 1.50 – 1.55 mm. Plots of effective breast diameter as a function of posterior-anterior position serve as a concise method for characterizing idealized 3D breast shape, and these parameterized curves are reported for breasts of different size classes based on the cup size metric. **Conclusion:** Breast CT acquisition techniques, combined with algorithms designed for determining specific breast metrics, were useful for classifying breast shape and skin thickness. Most breast dosimetry coefficients (DgN) are based on the assumption of a 4 mm skin thickness, and the thinner skin dimensions found in this study will likely have a small but significant influence (increase) on breast dosimetry in mammography.

TH-E-330A-02

A Local Fourier Description of Artifacts in Circular Cone Beam Computed Tomography

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Purpose: Circular cone-beam computed tomography is challenged by a lack of plane sums resulting in incomplete inversion of the radon transform. These missing plane sums have been identified by theory, and may be represented as a shift-variant cone of missing frequencies in the Fourier domain. The aim was to verify the presence of this cone in real data, and to show the dependency of resulting image artifacts on the frequency distribution of the imaged object. **Method and Materials:** A mini disk phantom (mylar/foam) was constructed to probe the local frequency response at various locations in the reconstruction space. Projections obtained using an experimental CBCT benchtop were reconstructed with 120 μm^3 voxel size using a modified Feldkamp filtered backprojection routine. Local Fourier transforms of the mini disks were analyzed for missing frequency data and compared with theory. Large disk phantoms of acrylic and cellular polyurethane were also imaged for further demonstration of the effect of varying the frequency content of the imaged object. **Results:** The cone of missing frequency was successfully identified in the mini disk phantom and agreed well with theory. Image artifact was found to have dependency on the local distribution of the object's frequency power spectrum relative to the cone of missing frequency information. Decreased resolution of the disks occurred when their dominant spatial frequency components were directionally aligned to coincide with the predicted null cone, as expected. Image reconstructions of large disk phantoms showed good detail in cellular disks even at locations that showed strong artifacts in the acrylic disk. **Conclusion:** The predicted null cone is observable in Fourier transforms of localized objects. Resolution in reconstruction is dependent on the relative frequency distribution of the imaged object; features that are most poorly resolved will be those with strong frequency components directed in the expected null space.

TH-E-330A-03

Reduction of Ring Artifacts in Cone Beam CT: Artifact Detection and Correction for Flat Panel Imagers

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Purpose: Defective pixels in a flat panel detector may be characterized by a nonlinear signal response drastically different from those in the neighboring pixels. They could lead to ring artifacts in cone beam CT. In this presentation, we will describe and demonstrate the use of a filter based calibration technique to detect these pixels. In addition, we will employ this technique as a flat field correction method to correct nonlinear signal response. **Methods and Materials:** To force the signal responses of all pixels to vary smoothly without sudden changes, we acquired images at fixed mAs but with various filtrations. Each filtered image is fitted to a smooth surface whose values are close to those of normal pixels but vary smoothly in the image. The ratios of the surface fit values to the original values were then computed on a pixel-by-pixel basis and used to map pixel values during subsequent image acquisition. This mapping would compensate for the nonlinear signal response associated with the defective pixels thus eliminating the ring artifacts. Using the surface fits as the reference, defective pixels were detected by automatic thresholding. **Results:** Using filter based calibration, defective (~0.035 %) pixels were successfully detected and corrected for. Therefore, ring artifacts were largely eliminated in cone beam CT images. A reduction in patterned noise artifacts in the projection images was also observed. The automated surface fitting procedure was found to be robust. **Conclusions:** Although the conventional flat field correction addresses non-uniform response across the detector, artifacts may still form as the pixel response varies with the beam quality and signal intensity. The filter based calibration procedure was successfully used to detect and correct for these artifacts.

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TH-E-330A-04

Investigation Into the Cause of a New Artifact in Cone Beam CT Reconstructions On a Flat Panel Imager

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Purpose: To investigate the source of and possible corrections for a new artifact seen in cone-beam CT (CBCT) images acquired using an a-Si flat panel imager (FPI) (Varian 4030CB). The new artifact is a bright circular region, tangent to the phantom edge, in images of elliptical and off-center phantoms. **Methods and Materials:** Temporal response of the FPI was measured using a step-wedge phantom, as a function of dose and irradiation history (10 cycles of 80 s exposure, with 9 off-cycles varying in time between 2 and 30 minutes, total time 1hour 20 min). A linear time invariant (LTI) model was developed by fitting multi-exponentials to the lag response from the step-wedge phantom. Anthropomorphic phantoms – pelvis placed centrally, and head placed off-center – were scanned and reconstructed with and without the developed correction. **Results:** Detector lag and continuous and significant monotonic gain increase (up to 10% for long irradiation periods) were observed during constant irradiation. Even after long periods of no exposure, with the detector being continuously read out, the gain did not return to the original, start-of-day value. Unlike Overdick et al., we did not see a saturation effect in the gain change. In CBCT reconstructions, differences up to 35 HU existed close to the edges of the artifact. After applying our correction model, differences were reduced to less than 10 HU. Our anthropomorphic phantoms did not generate streaks or comet tails, which other investigators have shown to be due to lag. **Conclusion:** We have determined that the source of the circular artifact observed is a non-ideal temporal response. This artifact can be mostly eliminated by applying a correction based on a LTI model. Future work will focus on more accurate modeling to completely eliminate the artifact. **Conflict of Interest:** Funding was provided by Varian Medical Systems.

TH-E-330A-05

Reducing Metal Artifacts in Cone-Beam CT by Tracking and Eliminating Metal Shadows in Raw Projection Data

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Purpose: CT streaky artifacts, caused by metallic implants such as fiducial markers or dental fillings, remain a challenge for automatic processing of image data. The effect of these metal artifacts is magnified in cone-beam CT (CBCT) images due to the fact that the soft tissue contrast is usually lower in these images and therefore is more sensitive to the artifacts. The goal of this study is to develop an effective offline processing technique to minimize the effect. **Method and Materials:** The geometry calibration cue of the CBCT system was used for tracking the position of the metal implant in the raw projection data. The 3D representation of the metallic object can be established from only two user-selected viewing angles. The position of the shadowed region in any view can be accurately tracked by re-projecting the 3D coordinates of the metal object. Then automatic image segmentation was performed to obtain a binary mask of the shadow at each projection angle. Finally, a Laplacian diffusion filter was used to replace the pixels in the masked region with the boundary pixels. The modified projection data were then sent back to the CBCT reconstruction engine to create a new CBCT image. Varian's Trilogy system was used in this study. The procedure was tested phantoms and patient cases. **Results:** It was demonstrated that this procedure can significantly minimize the metal artifacts and at the same time restore soft tissue contrast near the metallic object, even for the more difficult head and neck case with irregularly shaped dental fillings. Soft tissue visibility was improved drastically. Although not designed for on-line applications, the processing time is approximately 1-2 second per projection on an Intel Pentium processor at 2.6GHz. **Conclusion:** We have implemented an effective metal artifact suppressing algorithm to improve the quality of CBCT images.

TH-E-330A-06

Scatter Characterization in Cone-Beam CT Systems with Offset Flat Panel Imagers

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Purpose: X-ray scatter significantly degrades the quality of cone-beam CT (CBCT) reconstructions by introducing cupping and streaking artifacts. Simple correction techniques, based on subtracting a constant value across a projection, fail when the flat-panel detector is transaxially offset as is required to increase the reconstruction field-of-views for body scans. The purpose of this study was to measure x-ray scatter profiles for transaxially offset detectors and to characterize the resulting artifacts. **Method and Materials:** Data were collected on a table-top CBCT system. A pelvic phantom was imaged with a Varian 4030CB imager offset by 16 cm. Scatter was estimated by subtracting a nearly "scatter-free" projection data set, obtained by narrowing the axial collimator blades, from the full CBCT data set obtained with the blades in their fully open position. The resulting scatter estimate, valid in the narrow region of overlap, was extrapolated to generate a scatter estimate across the entire axial extent of the detector. This scatter estimate was then subtracted from the original CBCT data to generate scatter-corrected images. **Results:** The scatter profile in full-fan projections is relatively flat and symmetric. In contrast, in the half-fan configuration the measured scatter profile was asymmetric decreasing monotonically from the phantom-air boundary through the phantom center to the imager edge. The slope of this profile varied smoothly from the AP to lateral views resulting in reconstructions with abnormally bright and dark regions. Scatter correction using the measured profile proved effective. Cupping and doming amplitudes were reduced by 2/3. The average reconstruction error in the prostate region was reduced from over 120 HU to less than 40 HU. **Conclusions:** The asymmetries introduced by an offset detector result in non-uniform scatter profiles that generate unusual cupping artifacts. Our technique provides a means of characterizing these profiles. **Conflict of Interest:** Funding provided by Varian Medical Systems.

TH-E-330A-07

Evaluation of Scatter Mitigation Strategies for X-Ray Cone-Beam CT

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Purpose: Linac-mounted cone-beam CT (CBCT) imaging is a promising approach for improving the soft-tissue targeting accuracy of external-beam radiotherapy. However, the large proportion of signal due to scattered radiation results in large cupping artifacts and reduced contrast-to-noise ratio (CNR), hampering delineation of soft-tissue structures. The goal of this investigation is evaluate the impact of three scatter mitigation

strategies: scatter removal (SR), subtractive scatter corrections (SSC), and anti-scatter grids (ASG) on CBCT image CNR.
Method and Materials: A one-dimensional model was developed that to predict image noise, intensity, and contrast from the photon flux incident upon the flat-panel detector. Using previously published scatter-to-primary ratio (SPR) data, the impact of Poisson signal statistics, Gaussian readout noise, reconstruction filter, and total air-kerma on image uniformity, contrast, and CNR was evaluated. Using previously measured CBCT scatter and primary grid transmission; the impact of ASGs, SSR, and SR (e.g., via bowtie filters) was evaluated. In addition, synthetic polyenergetic CBCT projections of cylindrical low-contrast threshold phantoms, including compound Poisson process noise, were used to evaluate the impact of scatter mitigation on filtered backprojection (FBP) images. **Results:** Relative to complete SR, typical CBCT scatter reduces CNR by 30%–70% depending on patient diameter. Both 1D analysis and simulated images demonstrate that SSC effectively reduces cupping artifacts but does not improve CNR. ASGs with high scatter selectivity (>5) or large primary transmission (>0.7) modestly increase (20-30%) CNR for thick subjects. However, ASGs diminish CNR for smaller body sections or for exposure levels where additive noise dominates sinogram signal statistics. **Conclusion:** Correcting CBCT sinograms for scatter radiation is effective in reducing structural image artifacts but does not improve CNR. Antiscatter grids effectively suppress scatter artifacts but improve CNR only in selected clinical settings. This project was supported in part by a grant from Varian Medical Systems.

Imaging Symposium Room 330 D
Biomedical Imaging Research Opportunities Workshops (BIROW): A Guiding Consortium of Imaging Societies with NIH Support

TH-E-330D-01
BIROW - Biomedical Imaging Research Opportunities Workshop: Intersociety Project to Accelerate Biomedical Imaging Discovery and Application - Part II
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See Abstract Submission: TH-D-330D

Joint Imaging/Therapy Valencia B
Scientific Session
Imaging for Therapy Assessment

TH-E-ValB-01
Cell Proliferation and Tumor Hypoxia During Radiation Therapy
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Purpose: Tumor hypoxia is an important resistant component that significantly affects response to treatment. Our aim was to concurrently monitor cell proliferation and tumor hypoxia distribution during radiation therapy. **Materials and Methods:** Several canine subjects with soft tissue sarcomas were repeatedly imaged with PET/CT before, during and after radiation treatment. The tumors were treated with ^{60}Co in four 8 Gy weekly fractions. 3'-Deoxy-3'-fluorothymidine ([F-18]-FLT) and Cu-diacetyl-bis(N4-methylthiosemicarbazone) ([Cu-61]-ATSM) as surrogates of cell proliferation and tissue hypoxia, respectively, were used to follow the response. Approximately 200 MBq of FLT or Cu-ATSM activity was administered per scan. The CT data between the imaging sessions was co-registered and the corresponding PET data compared and analyzed. **Results:** Tumor response to therapy varied significantly between the subjects and even for different tumors in the same patient in case of multicentric disease. High heterogeneity of both cell proliferation and hypoxia (up to 50% in SUV) of the tumor was observed in several cases. Early proliferative response seems to be indicative of the overall tumor response. Both cell proliferation and hypoxia distributions changed during treatment, but their differential response remained rather constant. The distributions of cell proliferation and tissue hypoxia were often found to be complementary, but not exclusively. **Conclusions:** Concurrent monitoring of cell proliferation and tissue hypoxia represents a new dimension in tumor monitoring and provides basis for more efficient, biologically based treatment optimization. High heterogeneity of tumor kinetics and microenvironment together with spatially variable response calls for individualized approach to cancer management.

TH-E-ValB-02
Image Registration-Based Tool for Correlation Studies of Radiation-Induced Fibrosis and Local Dose-Related Parameters in Conformal Non-Small Cell Lung Cancer Radiation Therapy
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Purpose: Despite the clinical importance of radiation therapy (RT) induced pulmonary injury, methods to accurately predict the degree of RT-induced dysfunction are still lacking. Many investigators are trying to develop methods to relate dose-volumetric parameters to the risk of RT-induced lung injury, but no consensus has been reached about which of these parameters should be used. Other investigators are attempting to develop a dose-response curve for regional RT-induced damage and several local parameters like computed tomography (CT) density and single photon emission computed tomography lung perfusion and ventilation have been measured to allow an estimate of local injury. **Method and Materials:** A software tool was developed for the evaluation of the correlation between RT-induced fibrosis and local dose-related parameters for a group of non-small cell lung cancer (NSCLC) patients. Local dose-related parameters were determined using both conventional and Monte Carlo (MC) dose calculations algorithms. The relation between dose, calculated on the planning CT scans and RT-induced fibrosis, identified on follow-up CT scans, was established through linear registration. Subsequently, tissues densities were determined and automatic segmentation methods were developed for lung and fibrotic tissues. **Results:** One patient participating in a phase I/II NSCLC multi-center clinical trial was chosen for illustration. Patients' response to treatment was quantified by evaluating the variation of lung and fibrotic tissue volumes over the follow-up period. MC and conventional dose- and normalized total dose-response curves were generated for the RT-induced fibrosis. Fibrosis probability was shown to increase with increasing conventional and MC dose as well as with increasing conventional and MC normalized total dose. Moreover, fibrosis probability was also correlated with MC predicted hot spots in high dose regions.**Conclusion:** The presented tool allows a systematic numerical study of the relations between RT-induced fibrosis and dose, normalized total dose and MC predicted hot-spots in high dose regions.

TH-E-ValB-03
Tumor Volume Regression During Radiation Therapy to Predict Treatment Outcome for Cervical Cancer
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Purpose: To investigate the outcome predictive power of tumor volume measured by serial MR imaging (MRI) of cervical cancer, including the sensitivity and specificity to identify patients at risk of local failure. **Method and Materials:** Seventy-nine patients with cervical cancer stages IB2-IVA, treated with radiation/chemotherapy (RT/CT), underwent serial MRI: MRI 1(pre-RT), MRI 2(at 20-25 Gy/2 weeks), MRI 3(at 40-50 Gy/4 weeks), and MRI 4(at 1-2 months post-RT). Mean follow up was 6.2 (0.2-9.4) years. Tumor volumes (V_1,V_2,V_3,V_4) and regression ratios

(V_2/V_1,V_3/V_1,V_4/V_1) were measured by MRI 3D volumetry, and correlated with local tumor-control and disease-free survival using Mann-Whitney rank-sum test. **Results:** The volume data collected in this study were analyzed and the predictive power in terms of p-value to discriminate local tumor-control and disease-free survival was computed. The absolute tumor volumes (V_2,V_3,V_4) and the regression ratios (V_2/V_1,V_3/V_1,V_4/V_1) strongly correlated with local tumor-control ($p<0.001$). These parameters also correlated with disease-free survival, but only the last measurement (MRI 4) showed significant predictive value ($p=0.02$). Four methods had been developed to identify patients at risk for tumor recurrence (sensitivity 61%-100% and specificity 87%-100%). The most powerful method is based on the volume regression measured in MRI 3 and MRI 4 (V_3/V_1 >20% and V_4/V_1 >10%), which have a sensitivity of 89% and a specificity of 100%. Local failure can also be predicted as early as 2-3 weeks (MRI 2), the method of V_1 >40 cc and V_2/V_1 >75% shows a sensitivity of 61% and a specificity of 93%. **Conclusion:** MRI-based volumetric tumor measurement provides important predictive information about tumor response to the ongoing RT/CT. The methods developed in this study demonstrate a high specificity (87%-100%) for patients at risk of local failure based on long-term follow-up. These methods may classify patients who require more aggressive therapeutic intervention.

TH-E-ValB-04

Dosimetric Impact of Changed FLT Uptake in AML Patients Treated with Chemotherapy

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Purpose: The PET radiotracer [F-18]FLT (3'-deoxy-3'-[F-18]fluorothymidine), used to measure cellular proliferation, has the potential to validate the efficacy of chemotherapy. We investigate the effect of chemotherapy on the biological distribution and radiation dosimetry of FLT in patients with acute myeloid leukemia (AML). **Method and Materials:** Cellular proliferation was measured in adult AML patients injected with 5 mCi of FLT. Dynamic and whole body PET/CT scans were acquired one day prior to chemotherapy and one week after the completion of chemotherapy using a GE Discovery PET/CT Scanner. Organs were manually contoured in the PET images at multiple time points and time-activity curves were generated for each contoured organ. Organ cumulative activities, organ radiotracer doses, and total body dose were determined using the standard adult male model and the RADAR method of dose calculation. **Results:** The biological distribution of FLT changed as a result of chemotherapy and this redistribution affected individual organ and total body radiation doses. The toxic effect of the chemotherapeutic drugs on the leukemia cells resulted in a five-fold reduction of FLT activity in the bone marrow post-chemotherapy. This reduction in the bone marrow uptake was accompanied by a three-fold increase in FLT activities and radiation doses to the liver, kidneys, gallbladder, and adrenals while that of the spleen doubled. The total body radiation dose increased 30% post-chemotherapy, given identical bladder voiding conditions.**Conclusion:** Systemic therapies such as chemotherapy can lead to significant changes in the biological distribution and dosimetry of radiotracers used in PET imaging for treatment assessment. Knowledge of these changes could impact the administered radiotracer dose to patients. Care should be taken in determining a suitable radiotracer dose for each specific case in order to avoid unnecessary dose yet maintain appropriate signal-to-noise ratios.

TH-E-ValB-05

Analysis of Early Treatment Failure in Patients with Newly Diagnosed GBM Using Advanced MR Imaging

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Purpose: To seek imaging characteristics predictive of early treatment failure (EF) following concurrent radiation/chemotherapy (RT/CHT) in patients with newly diagnosed GBM s/p surgical resection using advanced MRI techniques ($3D^1H$ spectroscopy (MRSI), diffusion weighted (DWI) and perfusion weighted (PWI) imaging). Methods and Materials: 26 patients were imaged at 1.5T prior to RT/CHT (pre-RT) and immediately after RT (post-RT). Analyzed imaging parameters included peak heights of choline (Cho), creatine, N-acetyl-aspartate (NAA), lactate and lipid; Cho-to-NAA (CNI), Cho-to-Cr (CCrI) indices and excess-choline (Ex(Cho)); parametric maps of percent-recovery and apparent diffusion coefficient (ADC) were calculated. Mutually exclusive morphologic abnormalities were contoured as contrast-enhancement (CE), T2-hyperintensity (T2), resection-cavity, necrosis, and a reference for normal appearing white matter. Patients were categorized as EF if any new CE appeared or if the CE volume increased by >25% at post-RT. Imaging parameters were subjected to a Wilcoxon Rank Sum to test statistical significance between EF and non-EF. **Results:** 9/26 patients were classified as EF. Both patient groups did not differ statistically in terms of age, volume of CE or T2 at pre-RT. There were trends to higher Cho, CNI, and Ex(Cho) for the EF group at pre-RT, however, these did not reach statistical significance. Statistically significant findings within CE at post-RT were mainly associated with Cho and related indices and included lower ADC and %recovery values suggesting higher cellularity and increased leakiness of vessels in the EF vs non-EF group. **Conclusion:** Even though our preliminary data on 26 patients could not identify imaging parameters significantly different between EF and non-EF patients at pre-RT, the demonstrated trend encourages further evaluation of additional 31 additional patient data sets acquired at 3T in order to increase statistical power. In addition, the reported significant changes at post-RT suggest that the parameters may be valuable in assessing treatment effects.

TH-E-ValB-06

Quantitative Characterization of Tumor Vascular Dysfunction in High-Grade Gliomas Prior to and During Radiotherapy

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Introduction: Vascular properties within and adjacent to tumors may not be distinguishable by cerebral blood flow [CBF] or cerebral blood volume [CBV] alone, since the rates of CBV change may not be proportional in magnitude to CBF change. Hence, the empirical and physiological relationships between CBF and CBV were examined to estimate vasculature-specific hemodynamic characteristics in high-grade gliomas. **Methods:** Twenty patients with gliomas were studied with dynamic contrast-enhanced T2* MRI [DCE-MRI] before and during radiotherapy [RT]. CBF and CBV were calculated from DCE-MRI and the relationships between the two were evaluated using two different metrics: The physiological measure of Mean Transit Time [MTT]=CBV/CBF; and, Empirical fitting of CBV and CBF using the power law, expressed as $CBV=Constant*(CBF)^{\beta}$. Three tissue types were assessed, Gd-enhanced tumor volume [GdTV], non-enhancing abnormal tissue located beyond GdTV but within the abnormal hyperintense volume on FLAIR images [NEV], and normal tissue in hemisphere contralateral to tumor [CNT]. Effects of tissue types, CBV magnitudes (low[L], medium[M] and high[H] CBV), before and during RT, on MTT and β were analyzed by factorial ANOVA. **Results:** Both, MTT and β were significantly different ($p<0.009$) among the three tissue types. MTT increased from CNT(=1.60s) to NEV(=1.93s) to GdTV(=2.28s) ($p<0.0005$). The power exponent β was significantly greater in GdTV(=1.079) and NEV(=1.070) than CNT(=1.025), but β in NEV and GdTV were not significantly different from each other. β increased with increasing CBV magnitude. There was a significant decrease in MTT and a significant increase in β in tumor (GdTV) and peritumoral (NEV) tissue during RT compared with pre-RT values. **Conclusions:** β was strongly dependent on CBV magnitude and MTT on tissue type. Progressive abnormalities in functional characteristics of the vascular bed were noted, with significant disorder in tumor, but mild abnormality in peritumoral tissue. Early vascular response to radiation was first observed in functional rather than structural properties.

TH-E-ValB-07

Blood-Tumor-Barrier Permeability Changes in High-Grade Gliomas During Radiation Therapy Using DCE MRI

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Introduction: Radiation could affect vascular permeability in tumor and normal tissue. A previous study using high-resolution MR images and a contrast uptake index demonstrated that an increase in contrast uptake in the tumor occurs after 30 Gy and persists up to one month after radiation therapy (RT). This finding suggested that an optimal time window exists to

increase the efficiency of drug delivery to tumors. In this study, a quantitative method, *dynamic **contrast enhanced (DCE) MR imaging***, was used to assess tumor vascular permeability changes during RT, in order to maximize potential therapeutic benefit. **Methods:** Twenty patients with high-grade gliomas who underwent conformal RT participated in a MRI protocol. DCE T2* weighted images were acquired before RT, after ~30 Gy, and one month after the completion of RT. A transfer constant (K) of Gd-DTPA from blood to tissue was estimated voxel-by-voxel and used as a metric for assessment of vascular permeability. In the tumor volume (TV) defined on FLAIR MRI, statistically significant changes in K after ~30 Gy and one month after RT were evaluated, compared to before treatment, using a students' t test. **Results:** An average fractional volume of 29.6% in tumor manifested substantial contrast leakage with $K>0.005$ min^{-1} pre RT. In the TV where there was no substantial leakage pre RT, the mean K increased significantly from $K=0.0003$ min^{-1} to 0.0073 min^{-1} after ~30 Gy ($p<0.0005$) and to 0.0053 min^{-1} one month after RT ($P<0.003$). The fraction of TV that showed substantial contrast leakage significantly increased by 23% after ~30 Gy ($p<0.02$), but not one month after RT ($p>0.5$). **Conclusion:** DCE MR imaging reveals vascular permeability increases after ~30Gy in the portion of tumor where leakage is not substantial before RT. This finding suggests that the optimal time to administer chemotherapy is during the course of radiation therapy.

Therapy Scientific Session Room 224 A
Dosimetry Instrumentation and Clinical Measurements

TH-E-224A-01
Planning and Delivery of Dynamically Modulated Electron Radiotherapy

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Purpose: Evaluate capabilities of modulating electrons using the installed multileaf collimators, computing modulated electron dose distributions using Monte Carlo (MC) and optimizing the dose distributions. **Materials and Methods:** The modulated electron radiotherapy (MERT) evaluation was conducted with a Varian 120leaf MLC for 6-20 MeV. To provide a sharper penumbra, measurements were conducted with short SSDs (70-85cm). Aperture sizes (AS) ranging from 7-100mm (surface) were configured for measurements and modeling, using BEAMnrc MC code with 10^9 particles incident on the exit window and DOSXYZnrc for phantom dose calculations. Parameter included: Voxel size $0.2x0.2x0.1cm^3$, photon and electron transport energy cutoffs 0.01MeV and 0.521MeV, respectively. Verification measurements were performed with film and micro-ion-chambers. Calculated and measured data were analyzed in MatLab. Once validation of static fields was successfully completed, modulated portals (segmented and dynamic) were configured for treatment and composed for calculation using DOSXYZ. **Results:** Beam penumbra sharpness degraded with: decreasing energy and AS; and increasing SSD. PDD decreased significantly with AS. Nearly identical profiles when fluences were delivered by segmental and dynamic MLC sequences. The exception was in the peripheral and bremmstrahlung dose, which was higher in the segmented and dynamic deliveries, respectively. Calculations agreed with measurement within a distance-to-agreement of <3mm. With segmented delivery, we found it necessary to introduce small (~1.5mm) gaps between segments to retain ranges desired in the particular segment's path. The treatment time to deliver 5 segments of 3 energies, was ~90s, including console reprogramming. **Conclusions:** This study shows that MERT is feasible and provides conformal electron-beam dose distributions.

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TH-E-224A-02
A Systematic Analysis of Patient Specific IMRT QA Data

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Purpose: This is a retrospective analysis of patient specific IMRT QA data. The goal is to systematically evaluate IMRT plans and analyze factors that influence quantitative differences between calculations and measurements. **Method and Materials:** For each IMRT beam, planar dose is calculated using Pinnacle treatment planning system (TPS) at 10cm depth, 100 cm SAD in solid water with normal incidence of the gantry and Mapcheck measurement is performed accordingly. Absolute dose comparisons are performed between the planned and measured planar dose distributions with a 3% and 3mm criteria. A threshold is set at 10% of normalization point dose. The pass rates are categorized into the versions of TPS and delivery system. We also analyzed the outliers to see if we could *a priori* predict the differences between measured and calculated dose using a recently published Dose Uncertainty Model in Medical Physics. **Results:** A total of 427 plans with 2246 beams were analyzed; 57.7% of all beams have passing rates of at least 95%; 36% are between 85% and 95%; 6.3% are below 85%. The passing rate correlates strongly with the accuracy of beam modeling in TPS. The TPS version that explicitly modeled the MLC characteristics (leaf-end and leaf-side effects) had a better passing rate than the TPS version that had a simpler MLC model (60.7% versus 52.7% of at least 95%). The QA failure rate increases with the complexity of intensity modulation in a treatment field and with larger uncertainty of MLC beam model in the TPS. **Conclusion:** The accuracy of IMRT delivery is strongly correlated to the accuracy of MLC beam model in TPS. The pass rate for patient specific QA is strongly influenced by the complexity of the intensity modulation in a field. Strong relationship between position of failure and expected uncertainty was observed.

TH-E-224A-03
Orientation, Position, and Temperature Dependence On Optical Density Measurements When Using Sensitive Radiochromic Film and Fluorescent CCD Scanner

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Purpose: We report systematic artifacts that were found to occur when scanning a commercial radiochromic film (RCF) (GAFCHROMIC EBT) with a charge-coupled device (CCD) film scanner. Potential systematic sources of optical density (OD) measurement error were found be related to film orientation with respect to the scanner bed, film position on the scanner bed, and film temperature from repeated scanning. **Method and Materials:** We investigated the use of two flatbed CCD scanners that have been previously reported for use with the RCF, as well as two point densitometers that measure diffuse OD. Change in OD with film orientation was studied with small uniformly irradiated RCFs that were rotated and repeatedly scanned. A RCF from an IMRT QA measurement was scanned in portrait and landscape orientations to assess the magnitude of possible clinical errors. Film uniformity was assessed by evaluating profiles in the scan direction for large RCFs with graded uniform ODs produced by exposure to sunlight. A thermocouple was placed on the bed of a CCD scanner RCF was repeatedly scanned while recording temperature. **Results:** Sinusoidal variations of 15% were observed for rotating film measurements made with one CCD scanner (Epson) and 80% for the other (Microtek). The point densitometers did not demonstrate any variation with rotation. Changes in temperature in the range of 18-34°C lead to OD changes as large as 7%. The edges of the CCD scan beds demonstrated non-uniformities as large as 15%. **Conclusion:** Care must be taken to avoid these systematic errors when using RCF for clinical dosimetry. We recommend: maintaining the orientation of films; scanning in the central portion of the scanner bed; and limiting the number of consecutive scans.

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TH-E-224A-04
IMRT Film QA in a Heterogeneous Anthropomorphic Phantom

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Purpose: To study the agreement of heterogeneous IMRT treatment planning dose calculations with radiochromic film (RCF) and radiographic film (RGF) measured in anthropomorphic heterogeneous phantoms. We intend to use heterogeneous-phantom film dosimetry to improve IMRT

quality assurance (QA). **Method and Materials:** A commercial heterogeneous anthropomorphic head-and-neck phantom, with equivalent tissue bone, soft tissue and air regions was employed for dosimetry verification (CIRS, inc.). High sensitivity EBT radiochromic film (ISP, Inc.) and EDR2 radiographic film (Kodak) were employed simultaneously for film dosimetry. The phantom had 12 axial sections, each 25mm thick, with alignment pins and a compression plate. We selected a plane containing bone, soft tissue and an air gap for IMRT verification. The RCF and RGF were cut to match the selected plane, inserted between the sections and light sealed. A 6MV IMRT head & neck treatment plan with 7 beams was delivered using a commercial linac (Varian Clinac 2100/CD). The RCF was scanned avoiding artifact described in a companion work using a CCD film scanner (Epson 1680 scanner). The dose distributions were compared with the treatment plan. **Results:** Both RCF and RGF disagree with the treatment plan dose near the air cavities by 15%. Away the air cavities 5% agreement was obtained with RCF. Pronounced artifacts were observed in the RGF that were not observed in the RCF. **Conclusion:** IMRT dosimetry and quality assurance can be improved by using anthropomorphic phantoms that incorporate realistic heterogeneities such as bone, soft tissue and air gaps, and corrections to dose calculations can be applied. We hypothesize that RGF suffers from Cerenkov in air cavities and in less opaque phantom materials, and this will be investigated in further studies.

This work was supported in part by NCI grants R01-CA-100636 and N43-CM-52214

TH-E-224A-05

Absorbed Radiation Dose Measurement with a μK-Resolution Ultrasonic Thermometer

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Purpose: To develop a μK-resolution ultrasonic thermometer for non-invasive measurements of absorbed radiation dose in water and to characterize the intensity profile of radiation beams used for medical treatment. **Method and Materials:** Subtle temperature changes in water were measured by monitoring the phase of an ultrasonic disturbance propagating in it. The current system includes a thermally insulated water tank, an ultrasonic transducer, a frequency counter, and a Pulsed Phase-Locked Loop connected to a PC. The alpha-prototype was initially tested and characterized experimentally with time-controlled light pulses, and was subsequently evaluated with radiation heating from a therapy-level Co-60 source. The system was subjected to 30 one-minute, 50% duty cycle radiation exposures; the temperature history was recorded and analyzed. **Results:** Preliminary Fourier analysis of the temperature changes caused by periodic radiation heating showed that the absorbed dose rate corresponds to 1.80 Gy/min, deduced from a 0.43 mK (±3% 1) per cycle temperature rise in water. The estimated nominal dose rate at 81.6 cm from the source and 3.2 cm below the water surface is estimated to be 1.65 Gy/min. The discrepancy can be attributed to the non-standard water tank size and incomplete temperature calibration of the alpha prototype at test time. We expect to resolve these issues by equipping the system with a standard water tank and implementing a more advanced calibration procedure. **Conclusions:** The alpha prototype has been tested in Co-60 radiation and produced reasonable results. The feedback from these tests has recently been incorporated into the design of a beta prototype. The new system routinely detects less than 10 μK temperature changes in water and shows great promise for precise dose measurements and beam profile characterization. The new calibration procedure does not require external sensors and makes the system more portable and fully self-contained.

Research sponsored by NIST

TH-E-224A-06

Dosimetric Properties of 8 and 10 MV Photon Beams From a Flattening Filter Free Clinical Accelerator

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Purpose: In previous studies we indicated that removing the flattening filter from the beamline could improve some photon treatments. Optimal energies for treatments with unflattened beams may need to be higher than for the same treatments with flattened beams, in part owing to softer photon spectra. Since for flattened beams best results are often achieved at 6 MV, in this study of unflattened beams we investigated basic properties of 8 and 10 MV photon fields. **Methods and Materials:** This is a computational study based on the Monte Carlo method. We used the BEAMnrc program to model the Varian Clinac 2100 series accelerator. **Results:** Increasing the energy from 6 to 8 or 10 MV: (1) improves the efficiency of bremsstrahlung production. We calculated photon energy fluences (per incident electron) in air at 100 cm from the source for a 10×10 cm^2 field. The ratios of energy fluences of unflattened beams to flattened 6 MV beam were 2.29, 4.14, and 8.23 at 6, 8, and 10 MV, respectively; (2) improves beam penetration. The percent depth doses (PDDs) for a 10×10 cm^2 field at 10 cm depth were 63.6, 67.2, and 69.0 at 6, 8, and 10 MV; (3) reduces skin dose. PDDs for the above field at 0.3 cm depth were 76.5, 70.1, and 63.3 at 6, 8, and 10 MV, compared to 69.5 for a flattened 6 MV beam; (4) moderately increases nonflatness. The ratios of maximal to minimal doses within 80 % of the width of a 10×10 cm^2 field at 10 cm depth were 1.14, 1.18, and 1.23 at 6, 8 and 10 MV. **Conclusion:** The main dosimetric parameters of unflattened 6 MV beams can be improved by increasing the energy to 8 or 10 MV. **Conflict of Interest:** Research is sponsored by Varian Medical Systems.

Therapy Scientific Session Room 224 C

Monte Carlo Methods for Dose Verification

TH-E-224C-01

Generic Source Models for Commonly Used Clinical Accelerator Beams for Monte Carlo Treatment Planning

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Purpose: To develop measurement-based generic source models for clinical beams from commonly used medical accelerators for Monte Carlo treatment planning. **Method and Materials:** Source modeling and beam commissioning are key elements in the clinical implementation of Monte Carlo techniques. Monte Carlo studies of dose distributions in patients for radiation therapy would benefit from generalized models of accelerator beams especially when the model could be generated by direct measured data. Several previous studies on Varian accelerators have shown that it is possible to derive source model parameters from measured beam data. In this research generic measurement-based source model is developed where energy spectra are derived from depth dose distributions, fluence distributions are derived from measured profiles and the head scatter information is derived from in-air output factor measurement. The new photon source model uses a small extended photon source to represent primary photons generated in the target, a large extended source to represent scattered photons from the primary collimator, flattening filter and other linac components, and an extended electron source to represent contaminant electrons emerging from the treatment head. A four-source model will be used to reconstruct electron beams, which represent direct electrons, contaminant photons and electrons scattered from the first two scrappers of the electron applicator, respectively. **Results: and Conclusions:** An independent program is developed to generate source model parameters with measurement data automatically. The source parameters can be used by Monte Carlo dose calculation codes directly for phase space reconstruction. Comparisons have been done between dose calculated by Monte Carlo using this source model and measurement data for Varian and Siemens accelerators for different beams and energies. The results show excellent agreement (within 1%/1mm), which means that the measurement-based source model is acceptable for clinical use.

TH-E-224C-02

Performance Assessment of a Deterministic Method Incorporating Coupled Photon-Electron Transport for Photon Beam Dose Calculations On Acquired CT Data

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Purpose: To evaluate the performance of a neutral and charged particle deterministic solution method for external photon beam dose calculations using acquired CT data. Methods and Materials: The Attila® radiation

transport code, which solves the differential form of the linear Boltzmann transport equation for neutral particles and the Boltzmann-Fokker-Planck transport equation for charged particles, has been adapted for calculating dose distributions from acquired CT images. Comparisons were made with the Monte Carlo code EGSnrc (DOSXYZnrc) for a sample prostate treatment consisting of 8 10x10 cm^2 open beams with a realistic 6 MV photon spectrum. The Attila computational mesh consisted of 125,000 arbitrary tetrahedral elements, of approximately uniform size, which encompassed an imaged torso region. CT numbers were mapped to the Attila tetrahedral elements using one of four materials: air, tissue, adipose tissue, and bone, each having four discrete densities. Attila dose was determined at the image resolution by extracting the energy dependent particle flux at each 1x1x2.5 mm^3 pixel from Attila's calculated linear discontinuous finite element spatial representation, and multiplying by the energy dependent dose deposition response for that pixel material and density.

The DOSXYZnrc calculation used 2.5x2.5x2.5 mm^3 voxels, and was run until an average statistical uncertainty of 0.4% was achieved for voxels in the target region. **Results:** Computational times Attila and DOSXYZnrc were 36 CPU minutes (2.4 GHz Opteron processor) and approximately 8,500 CPU minutes, respectively. Employing a deterministic electron cut-off below 300 keV reduced the Attila computational time to 22 CPU minutes. Agreement between both codes was excellent in both high and low dose regions, with differences less than 2%/2mm for greater than 95% of points on a 2-D plane through the entire torso. **Conclusions:** A general purpose deterministic solver was successfully applied for dose calculations using CT image data.

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TH-E-224C-03

Implementation of Monte Carlo Code VMC++ for Photon Beam Treatment Planning

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Purpose: To implement the VMC++ Monte Carlo code for radiotherapy treatment planning of photon beams. The implementation includes the sampling of particles from a multiple-source model, modeling of accessories, and commissioning of the model based on beam data measurements. **Method and Materials:** In this work, the radiation output from a linear accelerator was modeled using a multiple-source model with separate sub-sources for primary radiation, extra-focal radiation and electron contamination. This approach enables the commissioning of an individual accelerator using a previously developed procedure, which determines the model parameters by minimizing deviations between measurements and superposition dose calculations. The same source model was used both for the superposition and for the Monte Carlo based dose calculation method. Physical wedges, MLCs, blocks and compensators were modeled by transporting particles sampled from the source model through a detailed geometrical model of the specific accessory. The MLC model accounts for tongue-and-groove, divergent leaf alignment, air cavities between adjacent leaves, and rounded leaf tips. **Results:** The accuracy of the developed algorithm was studied by comparing calculations to measurements for open fields, wedged fields, and irregular MLC apertures for 6 MV and 18 MV beam energies. The agreement between measurements and calculations was within statistical uncertainties for all of the studied cases. The calculation of a typical treatment plan takes from minutes to few hours, depending on the required statistical accuracy. **Conclusion:** It has been demonstrated that VMC++ with an optimized multiple-source model and particle transport through accessories results in accurate dose distributions in a wide range of conditions. The developed algorithm has acceptable calculation speed, and has large potential for improving dose calculation accuracy in complex situations and heterogeneous cases compared to traditional dose calculation algorithms. **Conflict of Interest:** Research sponsored by Varian Medical Systems Inc.

TH-E-224C-04

MMCTP, a Radiotherapy Research Environment for Monte Carlo and Patient-Specific Treatment Planning

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Purpose: To develop a flexible software package, on low cost hardware with the aim of integrating new patient specific treatment planning with Monte Carlo dose calculation suitable for large-scale prospective and retrospective treatment planning studies.

Programming Philosophy:
The *McGill Monte Carlo Treatment Planning* system (MMCTP) is designed as a software environment for the research development of patient specific treatment planning. The design includes a workstation GUI for treatment planning tools, and anonymous access to standard low cost hardware for MC dose calculation. **Results:** Before using MMCTP, treatment plans are converted into the so-called McGill RT format. This new file structure was designed for saving patient plans on the workstation. The current MMCTP features are: (a) DICOM and RTOG imports; (b) transverse/sagittal/coronal slice viewing for contours, CT scans, dose distributions; (c) contouring tools; (d) colour-wash and isodose line display; (e) DVH analysis, and dose matrix comparison tools; (f) external beam editing; (g) thumbnail CT navigation tool; (h) EGS/Beam calculation and XVMC patient transport for photon and electron beams. MMCTP uses a two-step process to generate MC dose distributions. The MC module controls egs/Beam and XVMC calculations. Input files, prepared from the beam geometry, are uploaded and run on the cluster using shell commands. Upon completion of XVMC, the GUI downloads individual dose files. **Conclusion:** The MMCTP GUI provides a flexible research platform for the development of patient specific MC treatment planning for photon and electron external beam radiation therapy. MMCTP uses an internal storage format that is flexible in that it allows for multi-instance multi-modality image information useful in the planning process. The visualization, dose matrix operation and DVH tools offer extensive possibility for plan analysis and comparison to plans imported from commercial treatment planning systems through well-documented image storage protocols such as DICOM.

TH-E-224C-05

Verification of a Monte Carlo Based Technique to Correct for Intrafraction Organ Motion

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Purpose: The most common planning technique to account for intrafraction organ motion is the application of a treatment margin to the clinical target volume (CTV). A uniform dose distribution is then planned for the resulting internal target volume (ITV). We have developed an alternative Monte Carlo based approach where the pattern of organ motion is directly incorporated into both the dose calculation and the optimization of IMRT treatment plans. We have verified the accuracy of this approach through a series of measurements performed with a moving phantom. **Method and Materials:** For each patient, a 4DCT was used to determine the pattern of respiration-induced anatomical displacement. The pattern of organ motion was incorporated into our Monte Carlo dose calculation by randomly sampling the isocenter location for each photon history. The resulting pencil beam dose distributions (incorporating motion) were used in the IMRT planning process. Treatment plans have been created for two phantom cases and three lung patients. Verifications were performed for two cases using a solid water phantom programmed for sinusoidal motion. **Results:** For the 3 lung patients in this study, the mean dose to the involved lung was reduced by 11.9% relative to the plans produced using traditional margin expansion. The verification measurements demonstrated a close agreement between the planned and delivered dose distributions. Incorporating organ motion into the IMRT planning process led to a 43.3% average reduction in the number of points that failed the gamma dose distribution comparison method. **Conclusion:** The use of Monte Carlo techniques to incorporate organ motion into IMRT optimization leads to significant improvements in normal tissue sparing and also results in improved agreement between planned and delivered dose distributions.

TH-E-224C-06

The Effect of Dental Restorations and Fixed Prosthodontics On Radiation Therapy Dose Distribution: A Monte Carlo Study

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Purpose: To investigate the effect of dental restorations, fixed prosthodontics, and implants on dose distributions in head and neck radiation therapy using Monte Carlo simulations. Specifically, we seek to understand how to prevent localized mucositis caused by backscatter dose. **Method and Materials:** Simplified models of a range of dental restorations, fixed prosthodontics, and implants were constructed using a representative sample of materials and configurations. These models were irradiated with a simulated 6MV lateral beam. The resulting dose distributions were compared against dose distributions on models without dental work. **Results:** Exposed dental alloy (Au-Pd) caused the most significant amount of backscatter, and corresponding hot spots in the dose distribution. Dental alloy which was surrounded by porcelain also caused backscatter hot spots, although lower compared to exposed metal. These backscatter effects do not appear in pencil beam dose calculations. This work showed that backscatter from dental work caused a dose enhancement of up to 40% at a distance of 1mm in the upstream direction for exposed metal surfaces. The dose enhancement from porcelain-veneered materials was up to 20% 1mm from the surface. The smaller enhancement was attributed to absorbtion within the ceramic veneer. Isodose lines for the backscatter formed a contour roughly conforming to the shape of the dental work. Beyond 3mm from the surface of the prosthodontic device, the dose enhancement had completely decayed. **Conclusion:** The metal content of dental restorations and fixed prosthodontics create significant enhanced dose to adjacent soft tissue. This is a major cause of morbidity. Since we have shown that the enhancement decays at a distance of about 3mm in tissue-equivalent material, we may reduce the likelihood and intensity of mucositis by displacing the soft tissue from the teeth with 3mm of tissue-equivalent material.

TH-E-224C-07

Monte Carlo Dose Calculation Procedure Using a 4D Motion Simulating Chest Model

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Purpose: To apply an anatomically detailed motion-simulating virtual patient model to the study of external beam treatment planning. **Method and Materials:** Breathing induced organ motion modeling may be classified broadly into (a) geometry-based and (b) physics-based methods. We have been developing a 4D motion-simulating chest model from a 3D tomographic model of the Visible Human images by varying the shape, size and location of the organs. Anatomical features where from the VIP-Man model that contains 80 segmented organs and tissues. The Non-Uniform Rational B-Splines (NURBS) surfaces of the organs were reconstructed to deform the organs by changing the control points. Clinically measured motion patterns were used to guide the deformation and motion. Four-field conformal photon beams were simulated for the treatment of a lung tumor case. The energy of the beam was assumed to be 6 MeV and the 4-field irradiation geometry was assumed to be AP, PA, RLAT, and LLAT. The lesion was simulated in the left lung and the PTV is designed as a sphere of 5-mm radius. The motion-simulating model is implemented into the EGSnrc code to calculate the absorbed doses using various non-registration registration methods. **Results:** The results showed that the dose to tumor could be up to 40% differences from phase to phase. DVH for this calculation showed less homogeneity for the whole breathing cycle. However, if the beam was gated to one phase, the result showed better homogeneity for target. **Conclusion:** A 4D chest motion-simulating model has been developed using the segmented Visible Human images. This study summarized procedures to develop a 4D motion-simulating chest model and demonstrated the usefulness of the model for Monte Carlo calculations. Possible ways to improve the motion simulation using physics-based tissue properties available from surgical simulation community are discussed.

Therapy Scientific Session Room 230 A

Radiobiology II

TH-E-230A-01

Can Dose-Volume Parameters Be Replaced with GEUD in the Treatment Planning Process?

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Purpose: Dose-volume metrics have often been correlated with outcomes and are often used to evaluate treatment plans. Unfortunately, when used for IMRT treatment planning, dose-volume metrics are computationally complex (non-convex) and can warp DVHs near the constraint dose. We investigate whether the generalized equivalent uniform dose (gEUD) can be made to highly correlate with different parts of the DVH curve by tuning the exponential parameter. If so, gEUD may be a smooth and computationally attractive replacement for dose-volume metrics in treatment planning and evaluation. **Method and Materials:** We correlated gEUD with various values of its parameter *a* and clinically applicable dose-volume constraints. Three datasets were used: lung, esophagus, and prostate, with 219, 263, and 291 patient plans, respectively. We tested values of *a* between -10 and 10 by intervals of 0.2 and in some cases tested values as low as -40. The dose-volume constraints tested include: V10, V20, and V30 for lung, V55 for esophagus, and D95 for prostate PTV and lung PTV. **Results:** For all cases tested, we found a Spearman correlation between 0.917 and 0.989 (mean correlation 0.956) with negligible ($<1x10^{-6}$) p-values. Values of *a* ranged from 0.4 to 3.2 for volume metrics and -7.8 to -27.2 for lung PTV and prostate PTV dose metrics (respectively). **Conclusion:** There is a significant and strong correlation between dose-volume metrics and gEUD for the datasets tested. The practical application of this is that for a particular dose-volume metric, we can find the value of *a* (the gEUD parameter) with the highest correlation and use the convex gEUD function in place of the non-convex dose-volume constraint in the IMRT optimization, thereby allowing optimization to be faster and more able to efficiently achieve a global optimum. **Conflict of Interest:** Partially supported by NIH grant R01 CA85181 and a grant from TomoTherapy, Inc.

TH-E-230A-02

Effects of IMRT Treatment Time Prolongation On Tumor Cell Survival

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Purpose: To quantify the loss in effective dose resulting from prolongation of treatment fraction delivery times associated with IMRT, and investigate the corresponding effects for neutron IMRT. **Method and Materials:** The effect of treatment fraction delivery time prolongation was investigated *in vitro* using human PC3 prostate and HGL21 and U373 glioblastoma tumor cell lines. Cells were maintained at 37 degrees Celsius and irradiated with photons from a conventional linac and with d(48.5)+Be fast neutrons. The delivery time for simulated, multiple-port fractions was varied from acute to 60 minutes for photon irradiation, and acute to 120 minutes for neutron irradiation. Physical dose ranges for cell survival analysis were 0.5-6 Gy and 0.16-2 Gy for photons and neutrons, respectively. **Results:** Prolonging photon delivery time (from initiation to completion of irradiation) from 5 to 45 minutes resulted in a loss in effective dose of 6% and 11% in the PC3 and HGL21 cell lines, respectively. A loss of <1% in effective dose was observed for similar prolongation of neutron irradiation of PC3 and HGL21, and photon irradiation of U373 cells. More clinically common prolongations of 5 to 30 and 5 to 15 minutes resulted in effective dose reductions of 4% and 1.5% for PC3, and 6% and 2.5% for HGL21. Application of typical dose response gradients would result in even larger percentage reductions in calculated TCP. **Conclusions:** This work indicates that prolonged fraction delivery times may have a significant impact on treatment outcome for tumors with a low α/β ratio and short repair half-time. These effects are significant at delivery times commonly associated with IMRT and are highly variable with cell type. Fraction delivery time should therefore be minimized to achieve the most predictable radiobiological effect. This work also demonstrates that the biological effect of neutron radiotherapy is independent of fraction delivery time.

TH-E-230A-03

Equivalent Uniform Dose (EUD) Based Optimization for IMRT Treatment Planning

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Purpose: To investigate whether IMRT optimization based on generalize equivalent uniform dose[1] (gEUD) objectives for target volumes and organs at risk (OAR) alike can lead to superior plans as oppose to multiple dose-volume (D&V) based objectives plans, for head and neck (H&N) and postmastectomy chest wall (CW) treatment sites. Methods and Materials: We applied gEUD–based optimization to obtain IMRT plans for H&N and CW cancer patients and compared them with the corresponding plans a) optimized with stringent multiple D&V objectives and b) optimized with the standard in-house physician requested (phys) D&V objective. The D&V optimized plans were created with objectives based on the resultant gEUD plans with the same weight of importance, in order to drive the optimization as close to the gEUD plan as possible. The plan comparison at this point was based on DVH analysis. **Results:** For all H&N and CW cancer patient in the study, we found that gEUD-based optimization led to superior sparing of OARs, even beyond the specified requirements, with the same or better target coverage when compared to either the phys-based or D&V-based plans respectively. In order to avoid dose inhomogeneities in the target volumes created by the gEUD-based optimization, use additional D&V objectives just for targets needed to be employed. **Conclusions:** The general conclusion drawn from our investigation is that the EUD objective function uses smaller number of parameters compared to the D&V and, allows a larger number of solutions with different DVHs but the same EUD. Thus, a better plan was delivered with EUD compared to multiple D&V objectives optimization for either the H&N or CW treatment sites. The use of EUD can allow the plan evaluation to be based on both DVHs and EUD. Details of the method will be discussed. [1]Niemierko A. Med. Phys. 26 (abstract), 1100 (1999).

TH-E-230A-04

Total and Partial-Body Zebrafish Irradiation

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Purpose: The zebrafish, *Danio rerio* has in recent years become a preferred model to study human disease. Our aim was to test the new micro-irradiator for its capability to perform basic radiobiology experiments, in particular to investigate relationship between radiation, apoptosis and inflammatory response. **Materials and Methods:** A novel micro-irradiator, which enables high dose radiation of biological samples below 1 mm, was used to irradiate zebrafish embryos at different age post-fertilization. Two experiments were performed – total body irradiation and partial body irradiation. In total body irradiation, the embryos were irradiated up to 40 Gy and the amount of surviving neutrophils as a function of time was analyzed. In partial-body irradiation, only zebrafish embryo tails were irradiated to 20 Gy and time-dependent apoptotic and inflammatory response was assessed. FITS-labeled neutrophil-specific antibody protein myeloperoxidase was used for neutrophil labeling and TUNEL assays were used for apoptosis labeling. **Results:** In total body irradiation experiments, little effect was observed at earlier time points post irradiation, but a sharp decrease in the number of neutrophils was observed at 72 hours post irradiation (hpi) suggesting that inflammatory cells can be completely ablated. In partial body irradiation experiments the inflammatory response seems to follow apoptotic response. Significant apoptotic and inflammatory activity was observed at few hours after irradiation, which slowly decreased to almost no activity as early as 24 hpi. **Conclusions:** Our new micro-irradiator can perform unique radiobiological experiments. Preliminary results investigating relation between irradiation, apoptosis and inflammation indicated severe post-treatment cell ablation effects for total body irradiation and early apoptotic and inflammatory response within 24 hours post irradiation.

TH-E-230A-05

Development of An Integrated Software Platform for Treatment Documentation and Outcome Analysis for IGRT

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Purpose: Information generated in IGRT is tremendous. The long-term goal of this work is to develop a software package (named RAPID, Research Analysis Platform and IGRT Databases) that is capable of storing patient diagnostic, treatment and follow-up data for IGRT, which documents treatment outcome, and allows dose-response analysis based on biophysical models. Presented here are several key components of this development. **Method and Materials:** The RAPID consists of a database, software tools and auxiliary applications. The database, developed using FileMaker software, includes modules for storing demographics, diagnosis, treatment, and follow up data. Diagnostic and planning images of different modalities (e.g., CT, PET, MR, US) and treatment verification images (e.g., CT, US, radiography) can be stored in DICOM format. Using an integrated auxiliary application these images can be brought into the desktop. The database is integrated with another software package, CERR, developed at Washington University, allowing display of contours and dose distributions on planning images. Various software tools are developed to perform dose response analysis that is linked to documented treatment outcome. For example, treatment related toxicity definitions for a given anatomic site were incorporated into the database, allowing standardized documentation of toxicity which, in turn, facilitates dose-response analysis. Calculations of EUD, TCP and NTCP are enabled based on 3D dose distributions. **Results:** The newly developed RAPID is found to be useful. Patient data collected in our clinic for two anatomic sites have been entered into the system. Analysis of treatment and follow-up toxicity was effectively carried out using the RAPID. With a FileMaker server installed to host the database, users can access password-protected information remotely. **Conclusion:** We have developed a software platform, RAPID, to facilitate storage and analysis of IGRT clinical outcome data.

TH-E-230A-06

Comparison of Correction and Model Based Dose Algorithms in Lung Cancer Retrospective Dose Recalculation and Treatment Outcome Evaluation

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Purpose: To perform a systematic comparison of the Monte Carlo (MC), convolution/superposition (CS), and equivalent path length (EPL)-based dose calculation algorithms for the purposes of outcomes modeling in lung cancer treatment planning. **Methods:** Several treatment plans (originally planned using EPL) from a large database of patients treated on a lung dose escalation protocol were retrospectively recalculated using MC and CS. Doses were computed in the homogeneous (unit-density) and heterogeneous geometries; homogeneous calculations were used to elicit differences in the beam models To evaluate algorithmic differences due to heterogeneity effects, beam model differences were minimized by adjusting beam weights in the homogeneous plans to achieve the same prescribed dose with each algorithm. These beam weights were then applied to the heterogeneous geometries. Absolute dose distributions were compared using: color-wash dose difference displays, isodose lines, EUD (for the target) and mean lung dose (MLD) and NTCP (for the normal lungs). **Results:** For the target, MC and CS-computed EUDs were in good agreement for both homogeneous and heterogeneous cases, with maximum dose differences of 1.2 Gy noted. Differences between EPL and MC (or CS) were generally much larger, in the heterogeneous plans extending up to 6 Gy. Differences in MLD computed with MC and CS ranged between 2% and 15% in the heterogeneous plans. These differences were similar in the corresponding homogeneous geometries, illustrating the importance of beam model disparities. For EPL, differences in the MLD and NTCP (relative to MC or CS) were much larger in the heterogeneous plans indicating systematic differences in the normal lung dose prediction. **Conclusion:** Evidence thus far is suggestive that discrepancies in dose computed with EPL and MC (or CS) will lead to differences in correlations of dose with outcome with respect to the target as well as normal tissue complications (radiation induced pneumonitis) and calculated NTCP.

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Estimate of Radiobiological Parameters From Clinical Data for Treatment Planning of Liver Irradiation

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Purpose: Several different dose fractionation regimens are being developed in clinical trials for liver irradiation. For example, RTOG is initiating a new hypofractionation regimen (RTOG 0438) to treat liver cancer patients. To evaluate the radiobiological equivalence between different regimens, which is useful in the design of these trials, requires

reliable radiobiological parameters. The purpose of this work is to estimate a plausible set of such parameters for liver tumor based on published clinical data. **Method and Materials:** A phenomenological expression inspired by the linear-quadratic (LQ) formalism was developed to fit a series of clinical survival data for radiotherapy of hepatocellular carcinoma patients. The data are from different institutes using different fractionation (e.g., 1.5, 1.8 or 4.88 Gy). The phenomenological expression consists of 6 fitting parameters including radiosensitivity parameters α and α/β, potential doubling time $T_{b,}$ and clonogenic cell number K. The expression considers the prescription dose, dose per fraction, overall treatment time and the elapsed time at which the survival data were collected. We have developed an algorithm to take into account the tumor cell repopulation during the elapsed time. **Results:** The newly developed phenomenological expression was found to fit well to the available clinical data. Based on the fitting, we have estimated a set of plausible radiobiological parameters for liver tumor: $\alpha/\beta = 12.8 \pm 1.0$ Gy, $\alpha = 0.013 \pm 0.002$ Gy, the potential doubling time: 123 ± 9 days, and colonogenic cell number: 1302 ± 47. Using this set of parameters we have calculated a series of dose fractionation regimens that are biologically equivalent based on BED. **Conclusion:** A plausible set of radiobiological parameters have been obtained based on clinical data. These parameters may be used for radiation treatment planning of liver tumor, in particular, for the design of new treatment regimens aimed for dose escalation.

Therapy Scientific Session Valencia A
IMRT Delivery

TH-E-ValA-01

On the Dose Delivered to a Moving Target When Employing Different IMRT Delivery Mechanisms

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Purpose: To investigate the influence of target motion on dose distributions generated using unmodulated open fields, solid intensity modulator (SIM), Step and Shoot MLC (SMLC) and dynamic MLC (DMLC). **Method and Materials:** For two lung cancer cases, four treatment plans were generated using Pinnacle[3] 7.9t consisting of an open field, SIM, SMLC and DMLC delivery on a Varian Clinac 600C/D equipped with a 120 leaf Millennium MLC. The coordinates (x, y, z, t) of the 4D motion trace for each of the tumors were determined using 4D-CT from which a 4D motion kernel was generated. For each beam used in the experiment, the beams-eye view tumor motion due to breathing was simulated using a computerized 2D tabletop apparatus. A MAPcheck diode array was incorporated into the apparatus for dose distribution analysis. Each of the four static treatment plans was delivered to the breathing MAPcheck ten times at various points of the breathing cycle. **Results:** The variation in diode dose readings within the tumor motion envelope was compared for the open field, solid, segmented, and dynamic IMRT deliveries. The open field provided the most uniform dose to the entire set of tumor mimicking diodes followed by SIM, SMLC, and DMLC IMRT, respectively. On an individual diode by diode basis over ten trials, the open field had the smallest average coefficient of variation of 0.122% followed by SIM (0.98%), SMLC (2.22%) and DMLC (3.88%) IMRT delivery, respectively. **Conclusion:** For the three IMRT delivery methods (SIM, SMLC, and DMLC), SIM consistently provided a more uniform dose to the tumor over many trials. SMLC performed as well as the solid modulators in many cases or was slightly out performed by SIM. DMLC consistently delivered the least uniform dose to the tumor over many trials.

TH-E-ValA-02

Simultaneous Multi-Pencil Fan-Beam-Based Intensity-Modulated Proton Therapy.

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Purpose: Intensity-modulated proton therapy (IMPT) will improve the conformality of proton radiotherapy while preserving target homogeneity and low integral dose characteristics. IMPT is currently delivered using a single scanned pencil beam by placing Bragg peak spots at predetermined points in the patient. Very short pulse lengths and low repetition rates will characterize inexpensive compact proton beam systems of the future such as the dielectric wall accelerator. Their pulse structure is not amenable to scanning a single spot. The use of multiple intensity-modulated pencil beams delivered in a fan beam is a simple approach to IMPT that can be used to upgrade current proton systems or with future accelerators. **Methods and Materials:** A fan beam is created with a pair of quadrupole magnets aligned so that the second magnet amplifies beam divergence initiated by the first magnet. A set of multiple range-shifters simultaneously adjusts penetration of multiple pencil beams. The actuation for the range-shifters is done out of the plane of the fan beam. The intensity is modulated for any pencil beam by placing a thickness, greater than the range in the protons, in that portion of the fan beam. This achieves binary (on-off) modulation as is used in x-ray tomotherapy. **Results:** Calculations show that a spot delivery rate increase of 8 times can be achieved with this system which would allow larger target volumes to be practically delivered with IMPT or used with pulsed systems with low repetition rates. The system could be used to deliver spot scanning with multiple pencil beams simultaneously or used to deliver proton tomotherapy. **Conclusions:** An intensity-modulated proton therapy system, based on multiple pencil beams issuing from a fan beam geometry, would decrease the delivery time for either continuous or low repetition pulse systems.

TH-E-ValA-03

Topographic Leaf-Sequencing Using a Genetic Algorithm

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Purpose: To develop a leaf-sequencing algorithm for fixed-gantry (*non-rotational*) treatment delivery on a commercial helical tomotherapy system (*HI-ART, TomoTherapy, Inc., Madison, WI*). **Method and Materials:** A genetic algorithm was used to determine the multileaf collimator (MLC) leaf open times for a series of fluence test maps generated from a tomotherapy machine with a fixed gantry angle of 0 degrees (IEC scale). A series of wedge shapes (15, 30, 45, and 60-degree) were mathematically created to test the algorithm's ability to produce simple modulations, similar to those which would be encountered in breast radiation therapy. **Results:** In general, the topographic treatment delivery yielded reasonable dose distributions. The agreement for the wedge cases was within ±2%, or 2-mm distance-to-agreement (DTA) in the high dose gradient regions. The central axis measured dose was between 3.6 and 4.2 percent higher than the expected dose for the wedge cases. For double peaks, the agreement was within ±2%, or 2-mm DTA across the entire measured film. For quadruple peaks, the agreement was within ±2%, or 2-mm DTA in the high dose gradient regions. At the first peak, calculated and measured agreed to within ±0.5%. The dose gradient between the first peak and the first valley was 5 percent per centimeter. The dose in the first valley agreed to within ±1.6% of the prescribed dose (at the first peak). The maximum error in the quadruple peaks occurred at the second peak, where the measured dose was 3.8% low (relative to the prescribed dose at the first peak). **Conclusions:** The developed algorithm produced calculated deliverable distributions that agreed well with the artificially constructed distributions. This delivery technique could be used for treatment of a whole intact breast. Additional work is needed to optimize the algorithm to improve agreement between the calculated doses and deliverable dose distributions.

TH-E-ValA-04

IMRT Delivery to a Moving Target by Dynamic MLC Tracking: Delivery for Targets Moving in Two Dimensions in the Beam's-Eye View

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Purpose: To outline a new modification of the dMLC delivery technique enabling the tracking of a target moving through rigid-body translations in a 2D loop in the beam's eye view and the accuracy of the delivery versus that of deliveries with no tracking and of 1D tracking techniques with patient intensity-modulated beams (IMB) is quantified.

Method and Materials: Leaf trajectories calculated in the target reference frame were iteratively synchronized assuming regular target motion. This allowed the leaves defined in the lab reference frame to simultaneously follow the target motion and to deliver the required IMB without violation of the leaf maximum-velocity constraint. The leaves are

synchronized until the gradient of the leaf position at every instant is less than a calculated maximum. The delivered fluence in the target reference frame was calculated with a simple primary-fluence model. The new 2D tracking technique was compared with the delivered fluence produced by no-tracking deliveries and by 1D tracking deliveries for 33 clinical IMBs. **Results:** The RMS difference between the desired and the delivered IMB was 15.4±3.3 MU for the case of a no-tracking delivery; 10.9±2.3 MU for the case where one component of motion was corrected and 6.8±1.6 MU for the 2D tracking delivery. The residual error is due to interpolation and sampling effects. The 2D tracking delivery technique requires an increase in the delivery time evaluated as between 0 and 50% of the unsynchronized delivery time for each beam with a mean increase of 13% for the IMBs tested. **Conclusion:** The 2D tracking dMLC delivery technique allows optimized IMBs to be delivered to moving targets with increased accuracy and with acceptable increases in delivery time. When combined with real-time knowledge of the target motion at delivery time this technique facilitates improved target conformity relative to no-tracking deliveries and allows margin reduction.

TH-E-ValA-05

Proton Lung Sterotactic Body Radiotherapy Treatment Method

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Purpose: Photon Sterotactic body radiotherapy has shown a great advantage over conventional treatment for stage I NSCC. Lung SRT has been limited by targets proximally to critical structures. Proton beam therapy can reduce the dose to the healthy tissue. Use of 4DCT introduces a great advantage in delineating the moving target and account for tissue motion in proton beam path. However, design of compensator is a critical factor for dose coverage in 4DCT. **Method:** We investigated the use of Free Breathing (FB), Maximum Intensity Projection (MIP) and Average CT (ACT) image data sets to obtain the best technique for proton beam treatment delivery. The target volume was the union of GTV on all phases contoured on MIP data set. Then MIP-GTV volume density was set to the average HU of the tumor to account for density variation due to motion on all data sets. The ITV was drawn by expanding 8 mm around the MIP-GTV. Apertures were designed by considering only beam penumbra and setup uncertainty. Distal and proximal distances and smearing were added to compensator design as described in reference (1). Compensators were designed on all three data using density corrected MIP-GTV. **Results:** The plans were calculated on all data sets. We evaluated compensators that were designed in FB, MIP, and ACT. Dose comparison was done based on the ITV dose coverage. Plans with compensator designed in MIP or ACT produce insufficient dose coverage when calculated in FB. **Conclusion:** The best coverage is obtained when compensator is designed in the MIP data set and plan is evaluated on ACT data set. The dose coverage was also verified on the inspiration and expiration phases of 4D data set using MIP compensator.

Reference:

1) M. Moyers, et.al. Int. J. Radiation Oncology Biol. Phys., Vol. 49, No. 5, pp. 1429-1438, 2001.

TH-E-ValA-06

4D DMLC IMRT Delivery to Targets Moving in Two Dimensions (in BEV)

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Purpose: To deliver proper IMRT to moving tumors using DMLC necessitate proper leaf sequencing technique to take care of the dynamic nature of the target. A complete compensation of motion can be achieved only if the compensation is in both the directions (direction along (*x*) and perpendicular (*y*) to the leaves motion). A technique to accomplish this is proposed. **Method:** The motion of the target is divided into two components. Then leaf trajectories to deliver the desired intensity modulated profile is calculated for all leaf pairs (LP) assuming the target is moving in one direction (x direction). Then leaf trajectories of all the leaf pairs are synchronized. Now the motion is compensated in x direction. As the MLC leaf can move only in one direction, the motion compensation in y direction is accomplished by switching the leaf trajectories of each pair appropriately i.e. say if the target is moving upwards in y direction, after a threshold value (value before which motion in y direction is neglected) the leaf trajectory of LPs are switched upwards meaning the leaf trajectory of LP1 is now followed by LP2 and trajectory of LP2 by LP3 and so on. The switching is in the other direction if the target is moving downward. Small dosimetric errors may occur while switching depending upon the time it takes to do the switch and also the threshold value after which switching happens. **Results:** An example of 4D-IMRT delivery to an irregular shaped rigid target moving in an elliptical pattern is shown. Other related delivery issues are addressed (dealing with target motion exceeding maximum leaf speed). **Conclusions:** This method of compensating the two dimensional tumor motion in BEV with one dimensional moving MLC while delivering IMRT meeting all mechanical practical and constraints is possible and promising for 4D-IGIMRT.

TH-E-ValA-07

IMRT Dosimetry with An Active Matrix Flat Panel Dosimeter

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Purpose: Dosimetric performance of a fully-customized Active Matrix Flat Panel Dosimeter (AMFPD) is reported for IMRT measurements in a solid-water phantom. **Method and Materials:** The AMFPD consists of a-Si:H photodiodes and thin film transistors deposited on a glass substrate. No scintillator screen or copper plate is present above the photodiodes. The device is operated in a continuous acquisition mode asynchronously with the radiation beam delivery at 0.8 fps. Prior to field delivery, a dark frame was acquired to take into account dark signal contributions to the radiation signal including any lag effects from previous irradiations. Dose was determined by summing the corresponding radiation frames (after subtracting from each frame a dark frame obtained prior to radiation delivery), correcting for defective pixels, applying a pixel-to-pixel gain correction, and then applying the measured dose response calibration curve. The response of the AMFPD was evaluated as a function of the applied bias voltage across the photodiodes, as this parameter affects dark signal, lag contributions, and sensitivity. In addition, the AMPFD response was evaluated as a function of dose, dose rate, and energy for static fields at 10 cm depth. For comparison, SMLC and DMLC IMRT fields were measured with the AMFPD and film, using standard methods for reliable film dosimetry. All comparisons were made in absolute dose values of cGy. **Results:** In continuous acquisition mode, the AMFPD maintained a linear dose response (correlation coefficient r^2>0.9999) up to 1040 cGy over the period of study (six months). In order to obtain reliable integrated dose results for IMRT fields, effects of lag on the radiation signal were minimized. Compared to film, the AMFPD results were excellent, generally within 2% /±2 mm. **Conclusion:** We found that the AMFPD can be used as a dosimeter at multiple depths in phantom for static, SMLC and DMLC IMRT fields