SCIENTIFIC ABSTRACTS AND SESSIONS

SUNDAY, JULY 24

Professional Symposium Room 6B
Professional Council Symposium: Current and Significant Economic Issues and Impact

SU-AA-P-6B-01
Structure and Function of ASTRO Health Policy and Economics Council: Medical Physicist Implications
D Beyers*, Arizona Oncology Services, Scottsdale, AZ

(no abstract submission)

SU-AA-P-6B-02
Process of New Technology Coverage and Current Medical Physics Reimbursement Issues
J Hevezi*, South Texas Oncology & Hematology, San Antonio, TX

The process of covering new technologies in medicine is complicated, both from the viewpoint of government agency reimbursement through the Centers for Medicare and Medicaid Services (CMS) and through the private sector carrier reimbursement entities such as Aetna, Blue Cross/Blue Shield and the like. The process is further complicated by coverage differences in the Hospital environment versus coverage in clinics and "stand-alone" treatment centers. Coverage decisions generally begin with CMS assignment of temporary coverage codes in the Hospital environment for new procedures and technologies. These take the form of the so-called "G" codes and are put forward for coverage by medical specialty societies when these professional organizations have agreed that the procedure or technology is "ready for prime time." Coverage decisions include actual dollar amounts for performing the procedure under current CMS rules. The medical specialty society then must submit the procedure to rigorous review for eventual coverage in the clinic or stand-alone center environment as the "G" code process is a time-limited coverage process.

Most carriers regard the randomized prospective clinical trial for a new procedure as the "gold standard" for coverage decisions. ASTRO and other organizations are lobbying for some surrogate to this process which will allow coverage for an effective procedure in a shorter time frame. Although other private carriers will generally follow CMS' approval process for new technology/procedures, they are not required to do so. In point of fact, private carriers can renege on a previously covered procedure if their medical advisory board decides the procedure will not be a benefit for its insurees. This has happened recently with the denial of coverage for one of the medical physics codes, CPT 77336 by one of the private carriers. Other examples of coverage denials and actions taken by the specialty societies to fight these denials will be presented.

SU-AA-P-6B-03
Correct Coding Guidelines for Medical Physicists: Tips and Hints For Getting It Right
S Granucci, CCS-P, Healthcare Reimbursement Specialist, Albuquerque, NM

Purpose: To provide attendees the essence of coding, reimbursement, coverage, rules and regulations for radiation therapy physics with a focus on new technologies such as IMRT, Accelerated Partial Breast Irradiation, Stereotactic Radiosurgery with Robotics, TomoTherapy and Stereoscopic Image Guided Radiation Therapy (IGRT). **Method and Materials:** Available Medicare codes and 2005 fees will be developed for both hospitals and free-standing practices for each service category. Any billing guidelines available will be collected from ACR, Medicare National and various Local Coverage Decision policies, as well as any published commercial and a few providers and vendors to provide insight into correct coding. In addition, the Correct Coding Initiative edit tables will be accessed to determine current bundling issues. All of this information will be compiled into the handouts. A good dose of coding and billing experience will be interjected into the presentation to help provide practical application to the information. Additional references and resources on web sites, manuals and publications will be provided. **Results:** All of these tools are designed to help healthcare providers focus on the business aspect of physics and these newer radiation therapies. They are intended to achieve results that add to the bottom line, and at the same time, to be compliant with government program requirements. **Conclusions:** The materials provided can be used for financial feasibility assessments for either adoption of new technology, or changes in practice setting. They will also allow internal checkup of current practice to assure correct coding options are in place.

Educational Symposium Room 6C
Education Council/AAPM Resources/Public Education

SU-BB-E-6C-01
Introduction - Education Council Chair
H Mower*, Lahey Clinic, Burlington, MA

SU-BB-E-6C-02
Educational Council Symposium On Residency Programs
E Klein*[1], B Clark[2], R Lane[3], D Mihailidis[4], K Krugh[5], J Esthappan[1], (1) Washington Univ, Saint Louis, MO, (2) British Columbia Cancer Agency, Vancouver, BC, CA, (3) UT M.D. Anderson Cancer Center, Houston, TX, (4) Charleston Radiation Therapy Cons, Charleston, WV, (5) The Toledo Hospital, Toledo, OH

In 1990, the AAPM published Essentials and Guidelines for Hospital Based Medical Physics Residency Training Programs (Report 36). Since then, many clinical residencies were initiated. Simultaneously, the Committee for Accreditation of Medical Physics Education Programs (CAMPEP) began a program of accreditation, charging the Residency Education Program Review Committee with this task. As of March 2005, there are 12 accredited programs with more applying. Today we will discuss; the forthcoming update to AAPM Report 36, the accreditation process and sources of funding, and most importantly we will hear from three resident graduates in regards to their training and how their careers have progressed post residency.

AAPM Report Number 36 gathers in one document the didactic knowledge and concepts that constitute the foundation of clinical medical physics. It lists equipment and procedures that embodies the breadth of medical physicist practice in radiation oncology, diagnostic imaging, and nuclear medicine. The new version acknowledges AAPM Report Number 79 "Academic Program Recommendations for Graduate Degrees in Medical Physics" as providing the standard for basic medical physics knowledge. However, didactic knowledge and concepts specific to specialized area of medical physics practice have been retained. Most of the equipment and procedures listed in the original report have been retained and many new ones have been added. Obvious examples include computed radiography, PET imaging, and IMRT.

CAMPEP offers accreditation of clinical residency programs in radiation oncology or medical imaging physics. The goal is to ensure a residency program provides rigorous and thorough clinical training (24 months) in a similar fashion to that provided by medical residency training programs. The graduating resident should be prepared to start the board certification process. The Process of CAMPEP accreditation requires a program submit a self-assessment report giving evidence of consistency clearly stated guidelines. After report review, a survey team conducts a program site visit to validate the assessment. If successful, accreditation is granted for 5 years with brief annual update submissions. To facilitate the application process, guidelines are available for download from campep.org. In addition, an application template is available from this link.

Funding is an important issue that has many solutions. CMS (formally HCFA) offers reimbursement to facilities with accredited programs. This falls under the paramedical education category, whereby portions of direct cost (salary & benefits) can be reimbursed. In addition, the AAPM (with

co-support from Varian) and ASTRO supply grants ideal for established or startup programs, respectively.
This symposium should be attended by, directors of physics programs, physics educators, and students contemplating residency programs.

Educational Objectives:
1. To understand the history and necessity of residency programs
2. Receive and update on AAPM Report 36 on Essentials and Guidelines
3. Learn about the accreditation process
4. Sources of funding for residency programs
5. Obtain a clear picture of residency from resident graduates

Joint Imaging/Therapy Symposium Room 6C
Memorial Session in Honor of John R. Cameron: Young Investigators Symposium

SU-CC-J-6C-01
Memorial
N Suntharalingam*, Emeritus Professor, Thomas Jefferson University, Voorhees, NJ

SU-CC-J-6C-02
A Monte Carlo Simulation of Out-Of-Field Radiation From An 18-MV Beam
S Kry*, U Titt, F Poenisch, D Followill, O Vassiliev, R Mohan, M Salehpour, MD Anderson Cancer Ctr., Houston, TX

Purpose: Patients undergoing radiation therapy are exposed to out-of-field radiation in the form of scattered and leakage photons, and at photon energies greater than 10-MV, neutrons. This secondary radiation may pose a health risk to the patient by inducing secondary cancers in long-term survivors; it is also a great concern for pregnant patients. Although estimations and measurements of out-of-field doses are possible, they are typically crude or time consuming and measurements may be only applicable to the particular treatment examined. A more robust tool is needed that can calculate accurately, and with relative ease, out-of-field photon and neutron dose equivalents. Such a tool has been developed with Monte Carlo. Method and Materials: A Varian 2100 accelerator and treatment vault, operated at 18-MV, have been simulated in detail with MCNPX (including head shielding and structure, gantry, and couch). The out-of-field photon dose and neutron fluence were simulated. Simulated photon doses were compared with those measured with TLD-700 in an acrylic phantom. Simulated neutron fluences were compared with fast neutron fluences measured with moderated gold foils in the patient plane. Neutron fluence can be converted to dose equivalent via conversion factors provided by the ICRP Report 74. **Results:** From a 10cm x 10cm field, the simulated out-of-field photon doses were found to agree, on average, within 10% of measured data over the range of 5cm to 40cm from the edge of the treatment field. Simulated neutron fluences were found to agree within 22% of measured data. **Conclusion:** A Monte Carlo model has been developed that is capable of calculating both the photon and neutron dose equivalent out-of-field. This tool is a substantial improvement on conventional calculations of the out-of-field dose from radiation treatments.

SU-CC-J-6C-03
Factors Affecting Remote Control Endovascular Catheter Steering for IMRI
F Settecase*, MS Sussman, TPL Roberts, Department of Medical Imaging, University Health Network, Toronto, ON, Canada

Purpose: Current applied to a wire solenoid wound at the tip of an endovascular catheter can be used to remotely steer a catheter in interventional MRI. In this study, we attempted to 1) optimize catheter visualization by comparing "real-time" pulse sequences, 2) derive and verify an equation that characterizes the relationship between the number of solenoid turns, applied current, catheter stiffness, and resulting catheter tip deflections. **Method and Materials:** Solenoids of 50, 100, 150 turns were wound on separate 1.8 F (using 44 AWG magnet wire) and 5F catheters (using 37 AWG magnet wire). Varying currents were applied using a DC power supply in the MRI control room. Images were obtained with 1.5 T scanner with the distal catheter suspended at 90 degrees to the main magnetic field in a water bath on the scanner bed, using ssFSE, spiral SPGR, FSPGR, FIESTA, and GRE-EPI pulse sequences. Deflection angles were measured on acquired sagittal images using eFilm. **Results:** ssFSE and FIESTA images had the highest SNR and the lowest sensitivity to local field inhomogeneity artifact. The deflection angleθ was predicted by the equation, $\theta = [nIAB/k]\sin(\gamma-\theta)$, where n is solenoidal turns, I is current, A is area, B is the scanner magnetic field, k is related to the catheter elastic modulus, and γ is the initial angle between the catheter and B ($R^2 = 0.9671$-0.9875). For a 1.8 F catheter and 60 mA applied, deflection was 31.5, 36, and 45.5 degrees from baseline for 50, 100, and 150 turns, respectively. Less flexible catheters required currents over 800 mA to cause deflection.over 20 degrees. **Conclusion:** SsFSE and FIESTA real-time pulse sequences are optimal for visualization of catheter tip deflection. The number of solenoidal turns, applied current, and catheter stiffness are important considerations for remote steering of endovascular catheters in iMRI.

SU-CC-J-6C-04
Theoretical and Empirical Investigations of Flat-Panel Imagers Incorporating Single- and Dual-Stage Pixel-Amplifiers Based On Polycrystalline Silicon Thin Film TFTs
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Purpose: To investigate the potential for achieving significant improvements in DQE at low fluoroscopic exposures and high spatial frequencies, as well as at substantially higher frame rates, through the incorporation of novel pixel architectures based on polycrystalline silicon thin-film transistors (poly-Si TFTs). **Method and Materials:** Detailed studies were performed on the signal and noise characteristics of a series of arrays incorporating poly-Si TFTs. These indirect detection designs involved three pixel architectures with a standard circuit, with a single-stage amplifier, and with 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. Detailed studies of these and other hypothetical array designs were also performed using circuit simulation tools. **Results:** These studies indicate that the high mobilities of poly-Si lead to potential frame rates at least an order of magnitude greater than those of conventional arrays with a-Si:H TFTs. In addition, the single-stage and dual-stage pixel-amplifier arrays exhibit signal gain (~×11 and ~×25, respectively) very close to that expected for these designs. Furthermore, while a net increase in the signal-to-noise performance was beyond the objective of these initial designs, analysis of the empirical data along with theoretical modeling strongly suggests that there are no intrinsic reasons precluding such performance enhancements. Finally, the non-destructive nature of the readout for pixel-amplifier designs enables repeated-signal-sampling, thereby creating new possibilities for noise reduction. **Conclusion:** These results encourage the hypothesis that substantial improvements in DQE performance and readout speed are possible through the incorporation of poly-Si circuits into 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.

SU-CC-J-6C-05
Intra-Fractional Variations of Anatomy During IMRT Treatment of Prostate Cancer
A Melancon*, R de Crevoisier, L Zhang, J O'Daniel, D Kuban, R Cheung, A Lee, R Mohan, L Dong, M D Anderson Cancer Center, Houston, TX

Purpose: The main goals of this study are to quantify the variations of pelvic anatomy during a single treatment fraction and to analyze the relationship of prostate and seminal vesicle (SV) motion relative to the bladder and rectum. **Method and Materials:** Twenty-six patients with locally advanced prostate cancer elected to participate in an IRB-approved intra-fractional motion study. Each patient received two CT scans with an integrated CT-linac system, one before and one immediately after a daily IMRT fraction including an ultrasound alignment. The pair of CT images was registered based on bony structure in the pelvic region using an in-house CT-to-CT 3D image registration software. The center of volume for both the prostate and SVs was used to assess the displacement of the same

structure after the treatment fraction. **Results:** Over the duration of one treatment fraction (20 ± 3 minutes) both the prostate and SVs showed statistically significant systematic trends in the superior and anterior directions of the patient's anatomy. The net change in bladder volume was huge (133 ± 78 cm^3), yet this increase did not directly coincide with large target shifts. Although the mean shifts in either direction were fairly small (1.8 mm and 1.3 mm for the prostate and SVs in the anterior direction), a few patients had shifts as large as 8.4 mm and 15.6 mm for the prostate and SVs respectively. These large shifts were highly correlated ($p=0.002$ and $p<0.001$) with large rectal volume increases caused from gaseous build-up in the rectum. **Conclusion:** Although the mean intra-fractional motion may not be clinically significant during an IMRT fraction, some treatment fractions could potentially miss portions of the target structures and/or include a larger volume of the anterior rectal wall for a small subset of patients (~20%) with large gaseous build-up.

SU-CC-J-6C-06

A Generalized Field Splitting Algorithm for Optimal IMRT Delivery Efficiency

S Kamath*, S Sahni, J Li, J Palta, S Ranka, University of Florida, Gainesville, FL

Purpose: The purpose of this work is to develop an algorithm for optimally splitting a large intensity-modulated field for delivery with a MLC into two or more adjacent subfields that maximizes MU efficiency, and to provide mathematical proofs that the algorithm is optimal in the most general cases. **Method and Materials:** The field split can be stated as the following mathematical problem: given a fluence matrix which exceeds the largest field size limitation of the delivery system, find two or three subfields, each of which satisfies the field size limitation constraint, that combine to give the original fluence map, and with the additional constraint that the sum of the delivered MUs of the subfields be minimized. In this general formalism, the subfields can overlap and the field split does not have to be in a straight line. We first construct an optimal MU leaf sequence for the large field ignoring the width constraint. The optimal field split is then generated by appropriate partitioning of the optimal leaf sequence into leaf sequences for the subfields. The overlapping region of the subfields creates a natural feathering area which is clinically desirable. **Results:** Compared to a simple field splitting that cuts through the center of a fluence map, our algorithm showed an average decrease in total MU of about 19% on 32 clinical fluence maps with the largest decrease in total MU of 45%. In many cases, the total MU of the split fields does not increase from the MU of the original sequence when the width constraint is ignored. **Conclusion:** We have developed an algorithm that solves the most general version of the field splitting problem for large intensity modulated fields. We provide rigorous mathematical proofs that the proposed algorithm for field splitting is optimal in MU efficiency.

SU-CC-J-6C-07

Helical Cone-Beam CT for Radiation Therapy

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Purpose: To develop the helical cone-beam scanning capability on a simulator CT system and apply a recently developed backprojection-filtration (BPF) algorithm to reconstruct exact 3D images from data obtained in this system. **Method and Materials:** Helical cone-beam CT is an emerging technology with many advantages over conventional CT scans, such as fast volume coverage speed, efficient use of x-ray power, and sufficient data for exact 3D image reconstruction. We developed the helical cone-beam capability on a simulator CT device (Acuity, Varian Medical Systems), which includes a kV x-ray source, a patient couch, and an amorphous silicon flat-panel detector (Varian PaxScan 4030CB). We fabricated a small motorized leadscrew mechanism on the couch of the Acuity, which allows for longitudinal translation of the patient couch at a constant speed as the gantry rotates. We applied the BPF algorithm to reconstruct exact 3D images from data obtained in this system. **Results:** A CatPhan phantom was used for data acquisition. 683 projection data were collected during a one-turn gantry rotation while the couch was translated longitudinally with a helical pitch of 187.2 mm. The x-ray source was operated at 125 kVp and 560 mAs. Before projection data were used for reconstruction, a number of corrections were performed, such as bad pixel, dark field, flood field, detector sag. We also applied simple corrections for beam hardening and scattering. 3D images were reconstructed from the corrected data by use of the BPF algorithm. **Conclusion:** We have developed for the first time the helical scanning capability on a simulator cone-beam CT system and performed a preliminary phantom study. The BPF algorithm was used to reconstruct exact 3D images from the helical cone-beam data. Such approach can readily be extended to cone-beam CT components on a LINAC to provide more accurate image representations of the patient.

SU-CC-J-6C-08

Automated Beam Direction Selection for IMRT Based On Geometrical Concepts of Viewability and Orthogonality

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Purpose: To develop a fast and reliable algorithm to automatically select beam angles for intensity-modulated radiation therapy (IMRT) treatment planning. We hypothesized that such an algorithm could be developed based on purely geometrical concepts as a pre-planning step. **Method and Materials:** We define any point in the target as *viewable* by a given beam if a ray from that beam, which passes through the point, does not intersect any critical structures (i.e., the point can be 'viewed' by that beam). The beam angle selection problem can then be generalized to the multi-set cover problem, a difficult (NP-hard) computer science problem. We also consider *orthogonality*, which captures beam non-overlap outside the target. We hypothesize that increasing 3-viewability (fraction of points viewable by at least 3 beams) and increasing orthogonality typically results in higher quality IMRT dose distributions. This was tested by comparing, for 30 random sets of 5 beam angles, the objective function based on 3-viewability and orthogonality vs. the final objective function value output of a weighted quadratic IMRT optimization. Our beam angle selection algorithm extends a greedy set cover algorithm and aims to find a set of coplanar angles that will make a maximum fraction of target points at least *k*-viewable while also maximizing orthogonality. **Results:** For an IMRT case where beam angle selection impacted IMRT objective function values, there was a strong correlation between the viewability-orthogonality objective function value and the final objective function value of a weighted quadratic IMRT optimization (Spearman correlation coefficient 0.63 ($p<0.0004$)). Our proposed algorithm determines beam angles for a typical plan in 2-4 minutes on a 2 GHz PC. **Conclusion:** We conclude that the purely geometrical concepts of viewability and orthogonality can be used as a basis for automatically and efficiently selecting IMRT beam angles using the class of algorithms proposed.

SU-CC-J-6C-09

Calculated Pwall Values in Clinical Electron Beams

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Purpose: Dosimetry of high-energy electrons beams is based upon absorbed dose to water standards and requires the use of ionization chambers with several correction factors. There is little information regarding the details of many of these correction factors for electron beam dosimetry. This study investigates the wall correction factor, P_{wall}, in high-energy electron beams for both cylindrical and parallel-plate chambers using Monte Carlo calculations. Dosimetry protocols use a wall correction factor of unity in high energy electron beams, despite some evidence that there may be an effect greater than 1%. **Method and Materials:** Monte Carlo calculations are carried out using the EGSnrc system. In particular, the user-code CSnrc is used to calculate the wall correction factor for a series of ion chambers using a correlated sampling variance reduction technique. The wall correction is computed as the ratio of doses to the air cavity for a chamber having a wall made entirely of water to that having a realistic chamber geometry. Calculations of the wall correction are performed for a variety of chambers at the reference depth in electron beams, using realistic electron beam spectra from clinical accelerators, ranging in nominal energy from 5 MeV to 25 MeV. **Results:** For parallel-plate chambers, the wall correction is between 1.5% and 1.8% at the lower energies and varies from 0.5% to 1% at the highest energies. For cylindrical chambers, the wall corrections are up to 0.7% for the energy range investigated. **Conclusion:** EGSnrc calculations of the wall correction factors for ion chambers in high energy electron beams show that this effect is, in many cases, greater than 1%. This differs significantly from dosimetry protocols, which assume a correction of unity in these beams.

Chamber-specific values of the wall correction for parallel-plate chambers are parametrized as a function of the beam quality.

SU-CC-J-6C-10

A Model for Technique Optimization of Dual Energy X-Ray Imaging

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Purpose: With increased clinical acceptance of dual-energy radiography, there is rising interest in the application of dual-energy techniques to other clinical problems. This paper describes the creation and experimental validation of a polyenergetic signal-propagation model for technique optimization of new dual-energy applications. The utility of this model is demonstrated with phantom verification of technique optimization of intravenous urography (IVU). **Method and Materials:** The model is composed of a spectral signal propagation component and an image-processing module. The spectral propagation component accepts detector specifications, spectra, phantom, and imaging geometry as inputs, and outputs detector counts and estimated noise. The image-processing module performs the dual-energy logarithmic subtraction and returns statistics such as contrast and CNR that can be evaluated in conjunction with Monte Carlo calculations of dose. The technique is then optimized and correlated to data from phantom images.
Hypotheses were investigated and model results compared with results from phantoms imaged in the laboratory. For IVU optimization, a phantom of polymethylmethacrelate and aluminum, and iodinated contrast agent filled tubes was imaged. Model and laboratory results were compared by dose, clinical suitability, and system limitations to yield optimized technique recommendations. **Results:** The model results accurately describe the images obtained in a low scatter environment. IVU-optimized dual-energy techniques differ from chest, and enable improved CNR over standard techniques without significant increases in dose, and with minimal degradation in the accompanying standard image. Alternatively, techniques without an accompanying standard image offer significantly lower dose and higher CNR. **Conclusion:** We have developed a model to predict optimized dual-energy acquisition techniques. Its utility has been demonstrated for IVU. For this application, model and phantom results indicate that significant improvements in CNR can be obtained without significant increases in dose compared to conventional techniques. **Conflict of Interest:** All authors are employed by GE Healthcare.

SU-CC-J-6C-11

Verification of IMRT Dose Distributions Using a Tissue Equivalent Plastic Scintillator Based Dosimetry System

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Purpose: Intensity modulated radiation therapy (IMRT) offers the potential for improved target coverage and increased normal tissue sparing compared with conformal radiotherapy. The complex fluence maps used in IMRT, however, lead to more challenging quality assurance with dose verification being labor-intensive and time consuming. An IMRT dose verification system has been developed using tissue equivalent plastic scintillator that provides easy to acquire, rapid electronic and directly digital dose measurements of a 2D plane perpendicular to the beam. **Method and Materials:** The prototype system consists of a water-filled Lucite phantom with a scintillator screen built into the top surface. The phantom contains a plastic mirror to reflect scintillation light towards a viewing window where it is captured using a CCD camera and a personal computer. Optical photon spread is removed using a micro-louvre optical collimator and by deconvolving a glare kernel from the raw images. System calibration is performed using radiation fields of known dose distributions. The system was evaluated by verifying a 5-field IMRT plan and comparing the results to a 2-D film dosimetry verification of the same plan. Resultant distributions were compared using 1-D dose profiles, 2-D dose difference maps and gamma factor analysis. A comparison of the time requirements for verification with each system was also performed. **Results:** Preliminary results acquired with the new verification system indicate agreement within 5% of 2-D film dosimetry. Gamma factor analysis shows excellent agreement over most of the distributions. The timing comparison of the verification systems highlights the efficiency of the new scintillator system for IMRT verification with a 50% reduction in time. **Conclusion:** Results from a 5-field IMRT plan verification using the new scintillator based system are very promising. With further development this system promises to provide a fast, directly digital, and tissue equivalent alternative to current IMRT verification systems.

Imaging Moderated Poster Session
Exhibit Hall 4E - Area 2
Imaging Dosimetry and Quality Control

SU-DD-A2-01

Activation of Metallic Prostheses in Patients Undergoing Fast Neutron Therapy

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Purpose: To quantify the induced activity and estimate the tissue dose from metallic prostheses in patients undergoing fast neutron therapy. **Method and Materials:** Three metal samples were tested, each having the dimensions of 5 x 5 x 0.5 cm^3. The metals were composed of alloys that have been used in prosthetic hip implants: cobalt-chromium, titanium-aluminum-vanadium, and stainless steel. The samples were irradiated with fast neutrons produced by d(48.5) + Be reaction in a superconducting medical cyclotron. The samples were placed in a tissue-equivalent phantom and irradiated in a 10 x 10 cm^2 field to a total dose of 9 Gy in 9 x 1 Gy daily fractions. Following each fraction, the sample was measured using a high-purity germanium gamma-ray detector. Spectra were taken at the following intervals: 1 minute, 1 hour, 2 hours, 3 hours, and approximately 24 hours after irradiation. **Results:** Activity 1 minute after irradiation averaged 5.4 mCi for CoCr, 4.9 mCi for Steel, and 9.3 mCi for TiVAl. Although the TiVAl sample had the highest initial activity, within 3 hours it had decayed the most. TiVAl also had the lowest activity 14 days after the last fraction. For a given dose, activities varied only slightly from day to day. An increase in dose delivered yielded an increase in induced activity. **Conclusion:** It appears that the TiVAl alloy would be the safest prosthetic material for patients undergoing fast neutron therapy, because of its fast decay rate. The presence of Co-60 in the CoCr sample is undesirable because of its long half life. Exposure to surrounding tissue as a result of the activation was negligible compared to the levels of radiation caused by neutrons. The level of activation should be considered only if the device is to be removed from the patient after neutron therapy.

SU-DD-A2-02

Investigation of Patient Doses Using a Tomographic Model for Diagnostic Radiology

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Purpose: In this study, the patient's doses from diagnostic radiology were calculated using the tomographic model and Monte Carlo simulation. The tomographic model offers a realistic replication of human anatomy, and more accurate dosimetric results **Method and Materials:** The tomographic model Korean Typical Man 2 (KTMAN-2) was segmented from PET/CT images and has $2\times2\times5mm^3$ voxel resolution. Three diagnostic x-ray examination procedures, abdomen AP, chest PA, and pelvis PA were considered in this study. Energy deposition within organs and entrance air kerma (EAK) were calculated using KTMAN-2 and Monte Carlo simulation. Also, organ dose comparisons were made for procedures of both a stylized and a tomographic model **Results:** For the chest PA examination, the lung dose assessed for the KTMAN-2 is 0.08mGy. The absorbed doses to the stomach, liver and thyroid in the KTMAN-2 exceed those within the stylized model by 279%, 161% and 90%, respectively. In the case of the abdomen AP examination, gut region and bladder receive a larger absorbed dose than other organs in KTMAN-2. The absorbed doses to upper large intestine and small intestine are higher than in the stylized model. But conversely, the absorbed doses to lower large intestine and bladder in stylized model are higher than in the KTMAN-2. For the pelvis PA examination, absorbed doses to gut region in stylized model are higher than in the KTMAN-2 **Conclusion:** The model's exterior trunk shape, shape and position of organs and shielding of bone are leading factors contributing to differences in organ dose. Due to the supine position during tomographic images acquisition, back of KTMAN-2 was pressed down and the abdominal organs are slightly shifted towards the thorax and the lungs are compressed. Thus the organ location difference between lying and upright posture should be corrected

SU-DD-A2-03

Influence of Equipment Variables Upon Cardiac Radiation Levels

E Nickoloff*, Z Lu, A Dutta, J So, J Moses, Columbia Univ, New York, NY

Purpose: The main goal is to demonstrate the effects of varying imaging equipment parameters have upon patient radiation dose in modern cardiac catheterization x-ray systems. The parameters examined include: pulse rate, Field-of-View (FoV), patient thickness, fluoroscopy versus record mode, SID settings and ABC programs. **Method and Materials:** A Siemens flat panel Axion Artis FC cardiac unit was used. The patient was simulated by sheets of acrylic varying in thickness from 10 cm to 30 cm. The exposure rate was measured at the entrance surface of the acrylic with an ionization chamber.
Results: The entrance exposure rate varied with the $(FoV)^N$ where $-2 < N < -3$.
The exposure rate varied directly with pulse rate in both fluoroscopy and record mode; in comparison to continuous or 30 pps, 15 pps reduced the radiation levels by 50%. The plus mode increased radiation levels by 40-50% and the minus mode reduced the levels by 40-50%. One minute of record imaging is equivalent to about 10 minutes of fluoroscopy. For both modes, the radiation levels increase approximately as an exponential function of thickness with an HVL in acrylic of about 2.8 cm. Maximum exposure rates for large patients can be 10 - 20 R/min in fluoroscopy and over 100 R/min in record mode. **Conclusions:** Although typical cardiac catheterization radiation levels are available for image intensifier and cine film systems, these data provide information related to a modern flat panel and digital recording system. Data about the relative effects permit significant dose savings to be realized by judicious selection of settings. In comparison to older equipment without these modern features, utilization of all the dose reduction steps can result in a dose savings of over 90%. **Conflict of Interest:** Some free software upgrades to equipment were provided during evaluations; no other financial conflicts exist.

SU-DD-A2-04

Direct Measurement of Pediatric CT Radiation Dose with a New Solid State Detector System

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Purpose: Because of potential risks, the determination of CT radiation doses is important for young children. Direct patient measurements are usually not practical. Many CT scanners provide a calculation of the $CTDI_{volume}$. A unique, tiny solid state dosimeter system (which has recently been developed) permits the instantaneous measurement of cumulative patient entrance radiation doses during clinical CT procedures. This study compared the calculated $CTDI_{volume}$ to direct measurements with this new detector in pediatric patients. **Method and Materials:** The new dosimeter system utilizes three tiny silicon detector chips 1cm x 0.5cm in size coupled to a small readout with thin cables. The system digitally displays the total accumulated dose. The energy response is +/-10% between 60 and 120 kVp. Radiation dose measurements during routine clinical head and body CT scans with a GE CT/i scanner were gathered for pediatric patients from newborns upto 18 years old. **Results:** Head and body data were separated and plotted in mGy per 100 mAs. The CT scanner calculated data showed no variation with patient size or anatomical location. The measured data, however, indicated radiation doses that were 2-3 times greater in small children and matched the calculated data for larger sizes. At the lower mAs values utilized for pediatric body scans, the measured radiation doses ranged from 2 to 5 mGy per procedure. At the higher mAs values for pediatric head CT scans, the radiation doses were 5-10 times greater than the body doses. **Conclusion**: This solid state integrating detector system provides a new tool for the accurate and instantaneous measurement of CT radiation dose that was previously unavailable. Moreover, the data demonstrate that the scanner calculated CT radiation doses can be in error by a factor of 2 to 3 times due to patient size variations and non-homogeneity of patient anatomy.

SU-DD-A2-05

Quality Assurance Methodology to Monitor Patient Dose in Interventional Radiography

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Purpose: The purpose of this preliminary quality assurance project is to use thermoluminescent dosimeters (TLD) to monitor the equivalent dose patients receive while undergoing interventional radiology procedures at our institution. **Method and Materials:** A TLD is placed centrally on the collimator face of two AP tubes in the angiography department for each patient exam. The TLDs are sent out weekly to be read by Landauer, Inc. Inverse square correction is applied to yield patient equivalent dose at the minimum and maximum possible distances to the patient entrance surface (source-to-skin distance, SSD). The inverse square corrected results are entered into a database and analyzed according to exam type and radiation dose threshold categories. All exams having an equivalent dose of greater than 2 Gy (skin erythema threshold) are red-flagged in the database. These red-flagged exams are then shared with the angiography section chief radiologist and technologist for feedback and corrective action with the attending physician. **Results:** Of the 1852 exams surveyed (from July 2003 through the present time), the equivalent dose for minimum SSD was less than 1 Gy for 94.0% of the exams and between 1 and 2 Gy for 2.6% of the exams. The skin erythema threshold dose of 2 Gy was exceeded for 3.1% of exams throughout this time period. It is encouraging that over 96% of measured equivalent dose are below the skin erythema threshold. The remaining 4% of measured equivalent dose were red-flagged for follow-up with the physicians responsible for the exam. **Conclusions:** This preliminary quality assurance and feedback mechanism is a quick and practical way to increase physician awareness of administered patient dose and whether skin injury dose thresholds have been exceeded. It is expected that this monitoring methodology will encourage physicians to practice ALARA.

SU-DD-A2-06

Improved Phantom and Method for Measuring the Low Contrast Detectability Performance of Fluoroscopic and Radiographic Systems

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Purpose: To develop an easy and reliable method of determining the low contrast detectability (LCD) performance of fluoroscopic and radiographic imaging systems **Method and Materials:** A phantom has been developed containing objects made of water equivalent material of varying contrast and diameters. Randomization of the positions of these objects is easily accomplished via the design of the phantom. To measure the LCD one would first decide what objects are visible in the fluoroscopic image. The phantom is then designed to allow one to easily see the actual positions of the objects in the phantom, once this visual judgment is made. Only correctly identified objects are scored. This method greatly reduces the subjectivity of present methods of performing this test, including the eventual memorization of a fixed "random" phantoms. The use of tissue equivalent materials for this test also gives a more true result of LCD for clinical studies and is much less biased by changes in kV and grid use. The use of this phantom can also be extended into evaluation of radiographic and digital imaging systems. **Results:** The use of this phantom provides accurate, reproducible measurements of LCD for fluoroscopic imaging as long as certain viewing precautions are observed for the fluoroscopic image. **Conclusion:** Current methods of evaluating fluoroscopic and radiographic image quality by means of LCD performance are relatively unreliable and quite variable between different observers. This new method allow for more accurate, reproducible LCD measurement

Joint Imaging/Therapy Moderated Poster Session
Exhibit Hall 4A - Area 3
Online and Real-time Image-Guided Radiotherapy

SU-DD-A3-01

Novel Geometric and Dosimetric On-Line Correction Strategies: Can Chance Work in Your Favor?

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Purpose: Investigate the efficacy of three novel geometric and dosimetric on-line strategies for adaptive radiotherapy in terms of workload and compliance with original treatment plan intent. **Method and Materials:** The three proposed on-line strategies are: Selective setup corrections (S1), Combined dose-per-fraction adaptation and setup corrections (S2) and Optimal dose-per-fraction adaptation (S3). In S1, setup corrections will only be performed if the displacement is "unfavorable" in terms of a radiobiological score based on equivalent uniform dose. The score function encodes a clinical preference for maintaining dose to the target, the critical organs or an arbitrary combination. S2 combines the selective setup corrections of S1 with a change in daily dose-per-fraction. In S3, only dose-per-fraction is a variable and is determined using a rigorous constraint stochastic optimization procedure. In a retrospective study the efficacy of these strategies was investigated. They were applied to a displacement dataset of 5 prostate patients. **Results:** For S1, maintaining the planned dose to the prostate is costly and requires many setup corrections. In contrast, a rectum-weighted score requires far less interventions and decreases the dose to the rectum on the order of 1.5 Gy, while approximately maintaining the dose to the prostate. Strategy S2 allows a considerable boost to the prostate dose for a preference to maintain the dose to the rectum. However, in this case, the bladder may exceed the dose limits. An equal-weighted preference is able to moderately boost the prostate dose while decreasing rectal dose and only moderately increasing bladder dose. S3 showed the biggest potential, however, it is computationally more involved. **Conclusion:** Flexible correction strategies can be designed using information about treatment anatomy and planned dose distribution. Such radiobiologically motivated strategies can be made highly compliant with initial treatment plan intent while often significantly reducing the number of interventions.

SU-DD-A3-02

Slice Based Image Guidance with Tomotherapy

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Purpose: To improve the temporal resolution of image guided radiation therapy with slice based CT images from treatment beams of tomotherapy. In slice based image guidance (SBIG), the patient position would be monitored nearly concurrently at the time treatment. **Method and Materials:** The experiment was performed on a benchtop tomotherapy (BT) and on a regular TomoTherapy Hi.Art 2.0 (TH2). BT consists of a 6MV source, a kV source, a standard CT detector and an actuator. A Rando phantom was scanned by BT with two different dose levels of 1 cGy and 0.1 cGy and a ROI was contoured on the lower dose image. The treatment beams that delivered conformal dose to the ROI were used to filter the sinogram of the higher dose scan. Based on multi-resolution analysis, the incomplete filtered sinogram was locally reconstructed to obtain ROI, which was fused back to lower dose image. A similar process was repeated with lung phantom on the TH2 with MLC modulation. The number of projections for BT is 600/rotation and for TH2 is 51/rotation. **Results:** Images reconstructed from the conformal beams on BT shows that without additional beams, the ROI can be reconstructed with good quality. Fine structures with width of 2-4 mm are clear. The MLC reproducibility is higher than 99.97% but the ROI image from TH2 was degraded by severe artifacts. **Conclusion:** The fusion image from BT suggests that a positioning accuracy of 2mm is achievable. The SBIG image from TH2 shows substantial artifacts, which mainly because that the number of projections are too few and the scatters from the multi-leaf collimator. The first problem can be solved by using pulses instead of the 51 angles from optimization. The second problem would require a modified optimization by adding conformal beams without MLC modulation.

SU-DD-A3-03

Evaluation of An Infrared Camera and X-Ray System for Gated Radiation Therapy

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Purpose: To determine the clinical feasibility of a gated treatment delivery system from BrainLab™. **Method and Materials:** The Exactrac from BrainLab™ is a localization system that uses both infrared cameras and x-rays. In gated mode, target location is determined by implanted fiducials. Breathing patterns are determined by infrared reflectors attached to the patient's surface. The User selects an x-ray trigger point and radiotherapy beam-on window relative to the breathing cycle. Multiple trigger levels may be selected to simulate a fluoroscopic mode to measure organ motion. Prior to clinical use feasibility tests including localization accuracy, gating window accuracy, and beam-on accuracy were performed. Patients with small lung lesions were selected for treatment and implanted with a 20 by 0.7 mm gold fiducial. Treatment planning CT scans were taken at expiration breath hold with internal and external fiducials present. **Results:** Localization accuracy was within 3mm when using 20% of the breathing cycle for beam on. To date, five patients with lung lesions were treated. Treatment times were approximately twenty minutes (standard dose fractionations). Implanted fiducials were well localizable in all patients. Target motion was on the order of 5mm average. Repeat CT scans showed implants did not migrate. The primary limitations with the system were related to breathing signal due to placement of external fiducials. **Conclusion:** Gating treatment technique from Exactrac™ has been used to treat lung lesions. This initial evaluation of the system verified the accuracy of the localization system under Gated mode. Implanted fiducials are localizable in patients, and gating is possible. The benefit of this system is the potential to decrease treatment margins and improve targeting. Continued evaluation of this system would help to define patient specific dose margins and beam-on windows for treatment.

SU-DD-A3-04

Strategies for Respiratory-Compensated Treatment of Lung Lesions

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Purpose: The CyberKnife Synchrony system allows respiratory motion compensated treatment of lung lesions implanted with fiducials, using a model of the relative motion of the fiducials and infrared diodes on the chest. Often implantation of fiducials in the lesion is not feasible because of the potential for pneumothorax. We compare the following two alternative strategies

1. Synchrony treatment with fiducials in the anterior chest wall
2. Non-Synchrony treatment with fiducials in the posterior chest wall

Method and Materials: The lung lesion patients were scanned using a GE Lightspeed Multi-Slice scanner to obtain 300 1.25mm thick slices through the area of interest during one breath-hold. This was performed three times covering full inspiration, full expiration, and mid-inspiration.
Fiducials were implanted percutaneously in the anterior and posterior chest wall. The lesion and position of the fiducials were delineated on all three sets of CT scans. If the motion of the lesion tracked the motion of the anterior chest wall fiducials, then a Synchrony plan was developed to treat the lesion as drawn on the mid-inspiration CT scan. If the lesion motion did not track with the anterior chest wall fiducials then a non-Synchrony plan was developed that treated the lesion as seen on all three sets of CT scans using the fiducials in the posterior chest wall for tracking. **Results:** Using anterior chest wall fiducials, the lesion motion tracked to within 1-2mm in X and Y, and 5-6mm in Z. The target was extended in Z to accommodate this. For non-Synchrony treatments the target volumes increased by 60 to 75% and the prescription isodose volumes increased by 65 to 90%. **Conclusion:** The treatment of lung lesions presents a difficult challenge especially if fiducials cannot be implanted in the lesion to allow full Synchrony treatment, but the techniques described will still allow treatment.

SU-DD-A3-05

Real Time DMLC IMRT Delivery for Mobile and Deforming Target

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Purpose: Assume image system in the treatment room provides the information about target motion/deformation during therapy in real time. The ultimate utilization of this information calls for applying it to the intensity modulated therapy so that intensity maps dynamically shift and deform in conjunction with the target motion. This presentation describes algorithms for the control of MLC leaves that deliver real time image guided therapy described above. **Method and Materials:** Target motions and deformations are modeled from data registered in real time. Real time IMRT aims for (1) delivery of predetermined intensity to target and surrounding tissue, (2) minimized time of delivery and (3) limitation of maximum speed of leaf motions to below the speed of maximum velocity

admissible for MLC. As goals (1) and (3) constitute indispensable conditions of IMRT delivery the minimization of the time of delivery (2) has to bee sacrificed. Thus the original set of equations relating leaf positions and velocities to deliver the predetermined intensity is set as the problem with over-restrictive conditions on leaf speeds. Random perturbations are then imposed over target motions and relationships between leaf velocities are appropriately modified to respond to perturbations. This assures that the slope of local intensity is properly shaped at each point of moving target with unpredictable real time registered motions of the target. **Results:** A sequence of representative examples delivering real time IMRT to moving/deforming targets is presented. Examples considered are characterized by varied intensities and different pattern of target motions/deformations. Deliveries of planned intensities, with and without corrections for changes in target motions/deformations, are calculated and inter-compared. **Conclusion:** MLC leaf motions can be controlled in real time so that image guided DMLC IMRT delivery is feasible provided image system in the treatment room communicates to MLC controller target motion/deformation data during therapy in real time.

SU-DD-A3-06

Model-Based Probabilistic Prediction of Tumor Respiratory Motion

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Purpose: The effectiveness of radiation therapy is degraded by respiratory motion, especially in the thoracic and abdominal regions of the body. Precise tumor localization, motion characteristics, and motion prediction are essential for accurate radiation dose delivery in real-time image-guided radiation treatment. To address this problem, we propose a model-based probabilistic solution for prediction of tumor respiratory motion. **Method and Materials:** By analyzing the historical motion data based on a finite state model, two probability distributions are proposed for knowledge discovery of tumor moving status. These probabilities can be used to determine the current motion state and capture transitions from one state to another. They are dynamically built and used in real-time motion prediction. Two prediction problems are studied for beam tracking and respiratory gating. The first requires continuous prediction of the exact tumor position, while the second requires predicting when the tumor will be IN or OUT of the gating window during radiation treatment. **Results:** Three metrics are used to evaluate the accuracy of the prediction **Results:** 1) the root mean square (RMS) error, 2) the gating duty cycle, and 3) the gating failure rate. Experiments on real patient data have been performed. Our model-based probabilistic prediction approach results in smaller RMS error, higher gating duty cycle, and lower gating failure rate than linear prediction. The same pattern has been observed for different patients, and with different latency. **Conclusion: A** probabilistic model-based approach can be used to characterize and predict tumor motion, and offer better prediction accuracy than linear prediction.

Joint Imaging/Therapy Moderated Poster Session
Exhibit Hall 4A - Area 4
Image Fusion, Registration, and Segmentation

SU-DD-A4-01

Multi-Day Multi-Modality Image Co-Registration

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Purpose: To develop a methodology for multi-day co-registration of multi-modality images taken throughout the course of radiotherapy, for the assessment of tumor response to treatment. **Method and Materials:** CT and PET image data sets of canines with various tumors were taken on a PET/CT scanner and were automatically co-registered to each other by the scanner software. Using a commercial software package, ROI segmentation was performed on the CT data to define the tumor boundaries. Each PET data set was then masked by the ROI of its aligned CT image and then rigidly co-registered with the masked PET data from other days. To align more specific uptake regions within the tumor, image warping was performed via landmarks placed on the co-registered multi-day PET data. **Results:** We found that ROIs can be roughly aligned by rigid registration of the outer tumor region as defined by the segmentation of CT data. Histogram correlation plots, aided by visual assessment, illustrated that normalized mutual information and Euclidean distance were the best-suited criteria for rigid registration, and that increased accuracy in co-registration was gained from image warping via landmarks placed on specific structures within the day-to-day rigidly co-registered PET data. A review of warping techniques on the co-registered PET data and generated data phantoms demonstrated that thin-plate spline warping provided the most complete warping of landmarked structures, while flow warping was not as aggressive with non-landmarked structures. **Conclusion:** Using this methodology of rigid registration of tumor boundaries defined from CT data, followed by inner feature warping of PET data proves to be an accurate and usable way to perform multi-day multi-modality image co-registration. Further investigations include additional contouring of segmented regions, adding scaling parameters to the initial registrations, and refining landmark placement and warping techniques.

SU-DD-A4-02

Fast Multimodal Image Registration Using Mutual Information and Variable Step-Size Grid Search Algorithm

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Purpose: A robust optimization algorithm, referred to as variable step-size grid search (VSGS), is presented for 2D/2D multimodal image registration, and evaluated using phantom and clinical imaging. **Method and Materials:** The VSGS optimization algorithm is based on recursive iterations of a geometrically scaled step-size, and is more likely to converge to the global optimum and be less insensitive to the local optima compared to traditional gradient techniques (i.e. Powell, quasi-Newton). As an optimization technique, it can be used with any objective function. Here mutual information was used as the similarity measure, and a multiresolution strategy was adopted to accelerate computation without adversely affecting robustness. VSGS was applied to the problem of automatic patient positioning in radiotherapy. The multimodal imaging consists of digitally reconstructed radiographs (DRRs), portal images acquired with electronic portal imaging devices (EPID), and the Varian linac-based on-board kilovoltage imager. EPID images were collected using the Siemens BEAMVIEW video EPID and the Varian AS500 flat-panel imager. **Results:** Validation was carried out using phantom and clinical imaging data. Measurements indicated that VSGS has an accuracy of 0.5 mm (or 1 pixel) and <0.5°, and required about 8 seconds per registration on a 2 GHz PC. VSGS has an accuracy equivalent to or better than the traditional optimization techniques depending on histogram or Parzen-windowing based mutual information calculations, but is more robust and faster computationally. This allows VSGS to be used for online real-time image guided patient positioning without requiring frequent user intervention to recognize shifts associated with registrations trapped in local extrema. **Conclusion:** VSGS can be used for online real-time image guided patient positioning to achieve more accurate patient positioning than using visual verification, and is sufficiently robust compared to traditional optimization techniques to make algorithm-based registrations sufficiently robust for routine clinical use.

SU-DD-A4-03

Spatial and Volumetric Comparison of Liver Tumors On CT and MR Using Finite Element Based Deformable Image Registration

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Purpose: To compare the spatial and volumetric differences in liver tumor definition based on triphasic IV contrast CT and Gadolinium contrast MR. **Method and Materials:** Changes in patient and liver position and differences in CT and MR imaging make an accurate comparison of tumor representation challenging, as deformation of the liver occurs. A deformable registration method has been developed to generate geometrically resolved views of the different image sets using finite element modeling to take advantage of the biomechanical relationship between the anatomical representations on each modality. The liver and liver tumors are contoured on the CT and MR, using a treatment planning system. A guided surface projection method is used to identify and account for the geometric discrepancies of the liver, allowing a direct comparison of the MR and CT tumors. **Results:** Triphasic CT and Gadolinium MR images were obtained at end exhale. Differences in tumor volume and

center of mass and in the surface area differing by greater than 3 mm in spatial position (PSA3) were measured for patients with liver metastases, cholangiocarcinoma and hepatoma. The tumor comparisons were done following registration of the liver to resolve geometric discrepancies. The average tumor volume change was 52% (19-121%). The average center of mass change was 0.4 cm (0.1-0.6 cm). The average PSA3 was 49% (28-60%). Initial results show that MR GTV was larger then CT GTV in patients with hepatoma, smaller in cholangiocarcinoma and variable in metastases. **Conclusion:** Deformable image registration improves the spatial correlation of the MR and CT defined liver GTVs compared to rigid body registration alone. This deformable image registration method preserves the spatial integrity of the tumor, while resolving the geometric differences between the MR and CT liver. **Conflict of Interest:** Research supported in part by Varian Medical Systems. LD is an ASCO career development award recipient.

SU-DD-A4-04

Registration of Prostate MRI/MRSI and CT Studies Using the Narrow Band Approach

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Purpose: High-field MR techniques makes possible to obtain high quality MRI metabolic images of the prostate to accurately identify the intra-prostatic lesion(s). However, the use of rigid endorectal probe deforms the shape of the prostate gland and the images so obtained are not directly usable in radiation therapy planning. This work applies a narrow band deformable registration model to faithfully map the MRI information onto treatment planning CT images. **Method and Materials:** The narrow band is a hybrid method combining the advantages of pixel-based and distance-based registration techniques, since the calculation is restricted to those points contained in a region around user-delineated structures. The narrow band method is inherently efficient because of the use of a priori information of the meaningful contour data. The deformable mapping is described by the B-spline model. The limited memory algorithm (L-BFGS) was implemented to optimize a normalized cross correlation metric function. It's convergence behavior was studied by comparing final metrics obtained in 100 registrations self-registering an MR image starting from 100 randomly initiated positions. The spatial performance of the algorithm was assessed by intentionally distorting an MRI image and an attempt was then made to register the distorted image with the original one. The MRI-CT mapping was carried out for two clinical cases. **Results:** The convergence analysis showed absence of local minima. The technique can restore an MR image from the intentionally introduced deformations with an accuracy of ~2 mm. On clinical cases the method was capable of producing clinically sensible mapping. The whole registration procedure for a complete 3D study took less than 15 minutes on a standard PC. **Conclusion:** Both hypothetical tests and patient studies have indicated that narrow-band based registration is reliable and provides a valuable tool to integrate the ER-based MRI/MRSI information to guide prostate radiation therapy treatment.

SU-DD-A4-05

Investigation of a 3D Gradient Based Method for Volume Segmentation in Positron Emission Tomography for Radiation Treatment Planning

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Purpose: Over the past few years Positron Emission Tomography (PET) is being used to supplement radiation treatment planning by assisting physicians in the determination of gross tumor volume. A number of studies have also been investigating the new possibilities that PET offers, such as guiding the delivery of a non-uniform dose in the tumor volume. Defining the surface of the tumor is an essential step in these applications; hence we investigated the use of a 3D gradient based technique for tumor volume segmentation. **Method and Materials:** We applied the gradient based technique to FDG-PET images obtained with a PET/CT scan of NEMA 2001 body phantom, with three spheres of different diameters whose FDG concentration was varied against an essentially constant surrounding activity. We measured the volume of the spheres gravimetrically, calculated them from the CT scan and we also estimated them from the PET images using three segmentation methods: 1) simple intensity thresholding on the raw PET data, 2) intensity thresholding on the background subtracted PET data and 3) a previously described 3D gradient based method. The obtained volumes were compared with the CT volumes. **Results:** The percentage error on volume estimation from the gradient based method varied from 15-38%. It had precision and accuracy similar to the background subtracted thresholding over the whole range of volumes and backgrounds, while it was less accurate than simple thresholding for low background activities, but worked better in regions of high background activity where the simple thresholding fails. **Conclusion:** We have successfully applied a gradient based volume segmentation technique to a set of phantom images. This method does not require any *a priori* information, only involves minimal user interaction and most importantly does not depend directly on image intensities. The results are promising, but further work is needed to validate its clinical use.

SU-DD-A4-06

Registration of Volumetric KV Or MV Cone Beam CT with Fan Beam CT

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Purpose: Kilovoltage (kV) cone beam CT (CBCT) provides the patient's volumetric information and is valuable for patient positioning verification. An important step in this application is the registration of CBCT acquired at simulation or before treatment with the planning CT (PCT). The purpose of this work is to investigate several specific issues involved in CBCT-TPCT registration and develop an effective algorithm to effectively utilize the volumetric imaging system for IGRT. **Method and Materials:** The PCT data were acquired using Picker PQ5000 scanner, and the CBCT images were obtained using Varian Trilogy OBI system. The image quality of CBCT is generally poor as compared with conventional CT: Low soft tissue contrast, artifacts/distortions, and limited width/length present practical problems for its clinical application. A BSpline based non-rigid image fusion software was implemented to provide voxel-to-voxel matching between PCT and CBCT. **Results:** For the phantom study, the quality of CBCT has little effect on the registration and the CBCT-PCT mapping was relatively straightforward because of the absence of motion artifacts. Examination of "bony" landmarks indicated that an accuracy less than 2mm was achievable. The patient registrations were complicated by artifacts and, in the cervix case, the limited field size of CBCT. While the bony landmarks can be registered to within 2mm, the motion artifacts complicated registration and caused a large uncertainty in the PCT-CBCT mapping. **Conclusion:** Low soft tissue contrast and artifacts of CBCT posed a challenge for CBCT-PCT registration. While continuous effect is needed to improve the CBCT, a robust registration tool that can cope with specific issues of CBCT is highly desirable to fully exploit the volumetric CBCT technology.

Therapy Moderated Poster Session
Exhibit Hall 4E - Area 1
IMRT Commercial Systems and Delivery

SU-DD-A1-01

A Dosimetric Comparison Between Laser-Proton Therapy and Photon IMRT

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Purpose: Advanced treatment modalities are being developed for radiation oncology to improve local control and normal tissue sparing. The goal of this study was to perform patient dose calculations for laser-accelerated proton beams and to compare treatment advantages using laser-proton therapy with conventional photon IMRT. **Method and Materials:** Laser-accelerated proton beams have broad energy and angular distributions. Small proton beams (beamlets) with limited energy spread were selected by a magnet system, and superimposed to generate spread out Bragg peaks (SOBPs) for proton therapy. The weights of the beamlets for the superposition were derived based on the Boltzmann transport equation and parameterization together with a gradient-search algorithm for plan optimization through intensity modulation. Monte Carlo simulations were performed for laser-proton treatment planning that used the same dose prescription and beam arrangement as those used in IMRT planning.

Results: Twenty prostate patients previously treated with IMRT have been included in this study. The comparison is made between IMRT planned on Corvus and laser-proton therapy on a home-grown Monte Carlo based inverse planning system. Our results show that better target coverage is achieved by proton therapy. Compared with IMRT, the target dose inhomogeneity ($(D_{5\%} - D_{95\%})/D_{95\%}$) can be reduced by 20-30%. The bladder dose can be reduced by up to 55% with proton therapy. Up to 40% of the rectum dose can be reduced using intensity modulated proton therapy. **Conclusion:** Significant improvement in target dose uniformity and normal tissue sparing can be achieved using laser-accelerated proton beams. Intensity modulation can further improve the dose distributions for proton therapy of prostate cancer.

SU-DD-A1-02

Commissioning and Clinical Implementation of Elekta MLC IMRT with Corvus Inverse Treatment Planning

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Purpose: This presentation details commissioning and clinical implementation of IMRT with the Elekta MLC and Corvus inverse treatment planning system. Particular attention is paid to features unique to this hardware and software that are not addressed in general IMRT guidance literature. **Method and Materials:** An Elekta Precise accelerator, equipped with 6 and 15MV photon beams and 80 leaf MLC, was commissioned for clinical usage IMRT with Corvus version 5.0. Data required by the planning system was collected using equipment and techniques consistent with current recommendations. A series of user defined intensity shapes, were used for initial testing of both energies by comparing calculated and film measured dose distributions. Five multifield clinical plans for each energy were compared to film in axial, coronal and sagittal planes, with an additional ionization chamber measurement at the intersection point of the three film planes. **Results:** When a dual off axis segment is defined by Corvus, a common occurrence in IMRT plans, the segment boundaries may be delineated by up to five different penumbra forming hardware combinations, 1) curved end MLC alone, 2) curved end MLC with backup jaw, 3) backup jaw alone, 4) divergent MLC side face alone and 5) divergent main jaw alone. This implies that both sets of jaws, in addition to the MLCs, must be calibrated to a relative accuracy of 0.2mm. When penumbra 1 and 5 were used in the Corvus pencil beam model, optimum agreement was found between plan and measurements. **Conclusion:** The physicist must be aware of leaf and jaw motion constraints that are unique to the Elekta Accelerator and how they are used in IMRT segment delineation by Corvus. When these factors are considered in hardware calibration and beam modeling, dose accuracy of 3% or 2mm is achievable over a range of stringent tests and clinical plans.

SU-DD-A1-03

Dosimetric Properties of Photon Beams From a Flattening Filter Free Clinical Accelerator

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Purpose: Investigation of the basic dosimetric properties of 6-MV and 18-MV photon beams, generated by a clinical accelerator, without the flattening filter. Comparison with flattened beams. Exploration of potential benefits of using nonflattened beams in radiation therapy. Application of a flattening filter free accelerator in intensity modulated radiation treatments. **Method and Materials:** In a Varian Clinac 2100 accelerator the flatting filter was removed from the beamline. Dosimetric properties of 6-MV and 18-MV photon beams were measured using ionization chambers and radiographic films. **Results:** As a result of removing the flattening filter: (1) the dose rate on the central axis increases by factors of 2.3 (6-MV) and 5.5 (18-MV), in 10×10 cm^2 fields at the depth of 10 cm; (2) the penumbra width decreases by 4-5% (6-MV) and 8-20% (18-MV) at small depths; (3) out of field dose close to the treatment field edge decreases by 15% (6-MV), 30-40% (18-MV) and tends to decrease more, farther away from the field; (4) the total scatter factor varies less with the field size; (5) multileaf collimator transmission decreases by 20% (6-MV) and 10% (18-MV); (6) dose per monitor unit increases to 2.15 cGy (6-MV) and 3.81 cGy (18-MV), according to the TG51 protocol; (7) the energy spectra of the nonflattened beams become softer, especially on the central axis; (8) dose close to the surface increases; (9) the ratio of dose on the central axis to that at 80% of field width (for 4×4 to 40×40 fields) increases to 1.1-1.7 (6-MV) and 1.2-3.2 (18-MV); (10) shapes of 6-MV lateral profiles change less with depth. **Conclusion:** With the flattening filter free accelerator potentially better treatments can be developed, characterized by substantially shorter delivery times, sharper penumbras, and reduced out of field doses. **Conflict of Interest:** Research is supported by Varian Medical Systems

SU-DD-A1-04

High-Speed Scintillation Camera to Study IMRT Delivery

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Purpose: The aim of this study was to accurately obtain the beam shape and fluence of all segments delivered during IMRT. We have developed an EPID employing a fast scintillator and a high-speed camera for this purpose. **Method and Materials:** A commercial high-speed camera was combined with a Gd2O2S:Tb scintillator. The camera was equipped with an 8-bit CMOS sensor, the pixel resolution was 0.635 mm, and the exposure time was 2.5 ms (to capture the scintillation pulses with a decay time of 0.550 ms but smaller than the 2.8 ms accelerator pulse period). The camera was synchronized to pulses from the accelerator pulse-forming network and gated to capture every possible pulse emitted from the accelerator, at ~360 pulses per second. An onboard 6 GB memory card allowed the capture of 60 s of delivery. A comparison of the MLC instruction files, log files, and camera data for a 42 segment IMRT beam delivery was performed. **Results:** The high speed camera allowed for capturing the delivered fluence without aliasing. Averaging 5 frames to 72 fps provided a signal-to-noise ratio that was sufficient to resolve leaf positions and segment fluence. The fluence from the log files and camera data agreed well except for the 1st segment where the log file appears to have missed the beginning of the delivery. The log files reported leaf motions at the end of 33 of the 42 segments. The camera measurements showed leaf motions in only 7 of the 42 segments. **Conclusion:** The high speed camera was able to resolve the IMRT beam output shape and fluence. Leaf motions were observed during beam-on for step-and-shoot. We found that the log files do not accurately predict leaf motion. Finally, we note that the camera resolution is adequate to resolve dynamic delivery.

SU-DD-A1-05

Real-Time Isodose Sculpting, CDVH Manipulation, and Delivery Efficiency Control in IMRT

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Purpose: We investigate the computational feasibility of tools enabling real-time adjustment of isodose contours, CDVHs, min/max statistics, and delivery efficiency in IMRT treatment plans. We are motivated to provide direct customization of the attributes used for clinical IMRT evaluation departing from the less direct, traditional prescription process. **Method and Materials:** We design an objective function to enable real-time adjustment of arbitrary dose distributions. We start from CORVUS inverse plans. To achieve each adjustment, we modify the objective function and apply gradient-based optimization within a discrete search space.

Dose planes, CDVHs, and statistics are recalculated and displayed following optimization. CDVHs and statistics are computed using stochastic estimation. Dose planes are computed on demand for three orthogonal views using multi-resolution grids.

We compare dose distributions before and after adjustment and record computation time. We use a prostate case, C-shaped thoracic case, and radio-surgical case treated with a Varian MLC, MIMiC, and BEAK respectively. We also evaluate dose accuracy by comparing the novel system's dose calculation with full CORVUS calculation. **Results:** We judged each tool to be effective in achieving its primary goal in all three cases. We note that local adjustments did induce some non-local changes. Isodose contouring, CDVH dragging, min/max adjustment, and delivery efficiency adjustment had average computing times of 6s, 14s, 30s, and 6s respectively running on a dual-processor, 2GHz PowerPC G5. Dose slices agreed so that 98% of pixels agreed within 5%, 5mm, while min/max statistics agreed to 0.65% RMS compared with CORVUS full calculation. **Conclusion:** Real-time manipulation of isodose contours, CDVHs, min/max statistics, and delivery efficiency in IMRT is feasible. Local manipulation has some long-range effects because of coupling. **Conflict of Interest:** The authors are employed at North American Scientific, NOMOS

Radiation Oncology Division. The system studied here has become Active Rx in CORVUS 6.0.

SU-DD-A1-06

Synchronized Delivery for DMLC IMRT for Stationary and Moving Targets

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Purpose: To eliminate tongue and groove (TG) underdosage effects during DMLC IMRT delivery for stationary and moving targets by synchronizing leaf pair trajectories using a non iterative algorithm. **Method and Materials:** Optimal leaf trajectories to deliver the desired intensities are calculated independently for all leaf pairs. The mid-time trajectories for all leaf pairs are also determined. From the mid-time trajectories of all leaf pairs one common synchronized mid-time (MT) trajectory is determined. Trajectories for all leaf pairs are reconstructed from this synchronized mid-time trajectory. Properties of the mid-time trajectory guarantee that no violation of velocity constraints occurs. The same procedure works for both moving and stationary targets. **Results:** The intensity delivered in the overlapped region without leaf synchronization, and with leaf synchronization, is examined using two examples. One example shows the leaf synchronization of five leaf pairs to deliver clinical intensity for stationary target and other shows ten leaf pair synchronization to deliver clinical intensity for moving target. The no collision property between the leading and following leaves of neighboring leaf pairs for MT-synchronized trajectories is assured. This property is illustrated in snapshots of the MLC leaves at different times of irradiation for moving targets. **Conclusion:** The mid time synchronization based solutions remove TG underdosage in DMLC IMRT delivery for stationary and moving targets. The delivery based on these solutions (i) removes TG underdosage in overlapped region in the sense that the intensity in the region is guaranteed to be equal to the lower intensity delivered by any one of two pairs of neighboring leaves (ii) facilitates simultaneous multiple leaf correlation and thus avoids iterative algorithms (iii) minimizes the time of delivery provided all constraints imposed on leaf motions are satisfied (iv) assures that no collisions between leading and following leaves of neighboring leaf pairs occur.

Imaging Moderated Poster Session
Exhibit Hall 4E - Area 2
Breast Imaging

SU-EE-A2-01

Evaluation Based On Breast Tomosynthesis of Amorphous Selenium Full Field Digital Mammography System

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Purpose: Our goal is to develop and evaluate breast tomosynthesis of amorphous selenium (*a*-Se) based full field digital mammography (FFDM) system. The clinical value of tomosynthesis will be to provide additional clinical information in order to improve decision making accuracy to either confirm or exclude a suspected abnormality, verify correct target for biopsies and analyze tumor margin better to get knowledge of the possible extent breast cancer. **Method and Materials:** The prototype of tomosynthesis full field digital mammography system which is used in evaluation is based on amorphous selenium flat-panel detector technology. The overall thickness of the selenium structure is 200µm, and the pixel size on this detector is 85µm. The total arc of the breast tomosynthesis system is 60° (-30° to +30°) and tomosynthesis sequence is performed at approximately 1-1.5 times the radiation dose of a conventional mammogram including 15 low-dose exposures. Reconstruction methods will be also discussed. **Results:** Based on the experimental results of this study, we believe that FFDM tomosynthesis can be used to determine whether a mammography finding is caused by a real abnormal lesion or by superimposition of normal parenchymal structures to be able to diagnose and analyze the findings properly. **Conclusion:** We need to be able to find screening and diagnostic method, which has high sensitivity as well high specificity to avoid unnecessary surgical interventions and to be able to detect breast cancer in its early stage. The technology has already proved its benefits in detecting early breast cancers and the capability of diagnosing breast cancers. Although FFDM tomosynthesis evaluation needs to concentrate on proving that it is clinically successful in the sense of increased sensitivity and specificity, with lower cost of workflow and reduced risk. **Conflict of Interest:** Mari Varjonen and Pekka Strommer are employees of Planmed Oy.

SU-EE-A2-02

Efficient Automatic Pre-Selection of Mass Lesion Candidates in DBT Breast Volumes

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Purpose: We are developing a computerized mass detection algorithm for the DBT breast volume. Extending existing concepts from projection mammography to 3D is computationally expensive. We are presenting an efficient algorithm for the pre-selection of lesion candidates from the DBT volume for further processing. **Method and Materials:** We applied a 3D radial gradient filter to the DBT breast volume. The convolution integral was limited to a shell. To account for variablity of mass sizes, volumes were filtered with multiple shell sizes. To increase computational efficiency, convolution was done in the Fourier domain. A maximum-intensity projection of each filtered volume was processed with a 2D tophat filter, using a structuring element of the same scale as the shell. Projections at multiple scales were combined by chosing the largest filter response, of the 3 scales, at a given pixel location. Algorithm performance was evaluated on a database of 21 breast volumes with 13 malignant and 8 benign lesions. Patient images were acquired at Massachusetts General Hospital. **Results:** The algorithm had a sensitivity of 100% at 22 false positives and 90% at 13 false positives per breast volume. For this pre-selection stage, the goal is to achieve high sensitivity. The false positive rate can be reduced subsequently through feature analysis. **Conclusion:** We have developed an efficien pre-selection stage for a 3D mass detection algorithm. The radial filtering stage uses a 3D filter which is less sensitive to reconstruction artifacts and responds more accurately to 3D spherical structures. Future work will include feature analysis to further reduce false positive detections. **Conflict of Interest:** RMN and MLG are shareholders in R2 Technology, Inc. (Sunnyvale, CA). DBK is patent holder for the technique of DBT and has received research funding from GE.

SU-EE-A2-03

Visualization and Identification of Breast Glandular Tissue in Breast CT Volume Data

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Purpose: Breast glandular tissue architecture complicates mammography image interpretation due to superposition. We have built a dedicated breast CT (BCT) scanner to produce volumetric images of the breast and begun a preliminary clinical trial in volunteers and selected patients. The purpose of this study was to evaluate visualization and identification of breast landular tissue patterns in BCT volume data and its potential to improve lesion detection compared to mammography. **Method and Materials:** A dedicated BCT scanner was constructed and previously described. Volunteer and patient imaging was performed using 80 kVp at doses comparable to a standard 2-view mammogram and reconstructed using a modified Feldkamp algorithm. BCT data of 512^3 voxels have an approximately isotropic resolution of 300 µm. Volume data were analyzed and viewed on a specially designed volume workstation and were displayed using blending, maximum-intensity-projection (MIP) and summation projection algorithms. Interactive review was possible for the entire volume. Breast glandular structures were identified based on CT number, voxel histograms and structural features. **Results:** BCT images showed impressive breast parenchyma and glandular structure detail with excellent contrast resolution. Volume rendering, especially summation projection, and thick slices provided optimization of viewing of ductal structures. Multi-planar slices permitted rapid scrolling through slices. Voxel CT numbers, histograms and architectural features were effective in differentiating glandular from fat, skin and connective tissues. MIP images clearly demonstrated calcifications. **Conclusion:** BCT provides high-quality volume data that enhanced visualization of breast glandular tissue and architecture compared to other breast imaging methods. Voxel CT numbers plus direct interactive viewing provided the mammographer clear

views of breast architecture and glandular tissues. Workstation display flexibility presented data appearing similar to mammograms plus additional tomographic slices further enhancing conspicuity of breast architecture. A small number of mammographically demonstrated cancers were readily identified in BCT data.

SU-EE-A2-04

Tone Mapping Operators for Contrast Enhancement of Mammograms

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Purpose: To investigate the effect of different tone mapping operators in contrast enhancement of mammograms. A concave piecewise linear operator is proposed and is compared to a convex (logarithmic) and linear operator. **Method and Materials:** Tone mapping is performed prior to contrast enhancement to elevate the lower intensities that mainly correspond to the skin-line zone. However, this leads to a loss in contrast due to compression of the gray levels. Gaussian band-pass filtering is then performed to enhance the contrast of the mammogram. Filtering highlights the structure of breast while suppressing noise and the slowly varying high-density structure. The filtering is done in the frequency domain and the image is mirrored and tiled prior to taking its Fourier transform to minimize edge effects. The tone mapping operators studied are logarithmic, linear and piecewise linear. The logarithmic operator has an adaptive base, the linear operator has constant slope in the intensities corresponding to the skin-line zone, and the piecewise linear operator has varying slope in those intensities. **Results:** The enhanced images were viewed on a calibrated Dome C5i display. The logarithmic operator compresses the intensities near the threshold excessively which results in substantial loss of information. The linear and piecewise linear operators do not compress to the same extent. The piecewise linear operator compresses more in the range where there is not much information than in the range where there is more information. Also, tone mapping decreases the magnitude of the intensity step-change from the breast region to the background. This reduces the ringing artifacts that result from the filtering operation **Conclusion:** The tone mapping operation improved the visual characteristics of the mammograms. Piecewise linear operator performed the best. The linear operator is comparable to the piecewise linear operator in most cases, though not as consistent. The logarithmic operator fared poorly.

SU-EE-A2-05

Accuracy in the Determination of Microcalcification Thickness in Digital Mammography

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Purpose: To study the factors which affect the accuracy of the microcalcification (MC) thickness determination in digital mammography, in particular, the contribution from scattered radiation. **Method and Materials:** The effect of scattered radiation on the accuracy of a MC thickness reconstruction has been studied using simulation. The GEANT4 code, assuming a scanning beam geometry, has been used to simulate photon transport through a tissue-like flat phantom containing 0.2-1.0 mm thick cylindrical MC and a pixelized detector (100 microns side). The influence of detector resolution has been analyzed by the simulation of small spherical MC embedded into the phantom. Background has been determined by a fitting technique for the signal/background description, using a Gaussian-like expression for the first, and a polynomial for the second. Measurements were carried out using a GE Senographe 2000D unit. **Results:** Our results indicate the possibility of reconstructing the MC thickness with accuracy of the order of 12.5%, including background, position and simulation uncertainties, when a 3 mm wide beam is used. The transversal size reconstruction for cylindrical MC having diameters larger than 1 mm, is of the order of 5%**.** Thickness reconstruction is found to be an alternative to signal to noise ratio for microcalcification detection. **Conclusion:** These simulations indicate that the thickness of dense objects larger than about 150 microns can be reconstructed using a digital mammography unit having 100 micron pixels and exposures equivalent to 1.5 mGy mean glandular dose.

SU-EE-A2-06

Non-Contact, Non-Invasive Breast Thermography Has Potential to Evaluate Treatment Response in Breast Cancer Patients

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Purpose: The purpose of the study is to determine the feasibility of using Breast Thermography (BT) to improve the evaluation of treatment response in breast cancer patients. **Method and Materials:** A protocol is underway at our institution that enlisted 17/30 breast cancer patients treated for: I) locally advanced breast cancer (LABC) on a phase I/II study of neoadjuvant chemotherapy (ChT) and hyperthermia (HT) (4/17); II) chest wall recurrence treated with radiation (RT) and HT (4/17); III) LABC treated with neoadjuvant ChT (2/17), and IV) chest wall recurrence treated with ChT (7/17). The patients are imaged before and after the completion of the prescribed treatment. Patients from group II were imaged before and at the end of each week of treatment. Six of the seven patients in group IV were either not due for follow up at the time of this report, or haven't reported yet. For the patients in group I, BT was used in conjunction with other imaging and pathologic studies to correlate the skin thermal signature with physiologic (perfusion, oxygenation) and pathologic (size, grade, hormonal receptor status, and lymphovascular invasion) characteristics of intact breast tumors. For patients in the other groups, either established imaging studies (MRI, PET), or clinical inspection was used to correlate and validate the BT data. **Results:** Preliminary results demonstrate that the BT data correlates well with MR and PET. Thermographic changes in the breast as captured with a high resolution infrared camera correlate with treatment response as demonstrated by clinical exam and pathologic response (in patients where this data was available). **Conclusion:** Breast Themography contributes additional information regarding treatment response than just visual clinical inspection in patients with chest wall recurrence or inflammatory breast cancer. This non-invasive, non-contact, cost-effective tool has potential for evaluating patients undergoing neoadjuvant therapies for breast cancer.

Joint Imaging/Therapy Moderated Poster Session
Exhibit Hall 4A - Area 3
Image-Guided Radiotherapy Strategies - Other Techniques

SU-EE-A3-01

Evaluation of Image-Guided Radiation Therapy (IGRT) Technology and Their Impact On the Outcome of Hypofractionated Prostate Cancer Treatments: A Radiobiological Analysis

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Purpose: To evaluate various image-guidance technologies and their potential impact on the outcome of hypofractionated prostate cancer radiation therapy to mitigate against geometric uncertainties. **Method and Materials:** Five prostate cancer patients were analyzed. All patients were planned twice with an 18MV six-field conformal technique with a 10 and 5 mm margin sizes, with various prescription doses (35 to 70 Gy) of equal late complications (assuming normal tissue α/β = 3 Gy). The various target localization techniques simulated were (1) laser alignment to external tattoo marks, (2) alignment to bony landmarks with daily portal images, (3) alignment to the clinical target volume (CTV) with daily CT imaging, and (4) the repeat of technique (3) with daily monitor unit updates to account for patient shape changes. The impact of uncertainty in the assumed α/β value for the prostate was also assessed. **Results:** For all treatment schedules simulated, technique (4) achieved the ideal condition most closely (i.e., $\Delta TCP = TCP_{technique} - TCP_{plan} \approx 0$ %), then followed by (3), (2) and (1). As the number of fractions decreased (i.e., increasingly hypofractionated), the ΔTCP generally decreased for all techniques. Because the hypofractionated schedules were designed to keep late complications constant, the NTCP values were also relatively constant for all treatment schedules. Generally, the average NTCP values were lower than the plan for all techniques. However, the most effective way to reduce NTCP was to reduce the margin size from 10 to 5 mm. Overall, the uncertainty in α/β values had a far more influence on the outcome of the

hypofractionated treatment than would the geometric uncertainties. **Conclusion:** This study suggests that, although the impact of geometric uncertainties increases as the number of fractions decrease, the reduction in TCP due to the uncertainties does not significantly offset the expected gain in TCP by hypofractionation.

SU-EE-A3-02

Feasibility Study of Dose Compensation in Image-Guided Radiotherapy (IGRT) of Prostate Cancer

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Purpose: In image-guided radiotherapy (IGRT), volumetric information of patient anatomy at treatment conditions is made available with in-room imaging devices such as cone-beam CT. Planning margin can therefore be reduced significantly through online guidance. However, uncertainties such as organ deformation and intra-fraction motion cannot be considered this way. The purpose of this study is to investigate the use of offline dose compensation to further reduce the margin safely. **Method and Materials:** In IGRT, CT scan of patient is performed at each fraction. Setup error and inter-fraction rigid motion are corrected online through couch translation and collimator rotation. The regions of interest are registered offline between treatment and planning CTs using a finite element method to account for non-rigid motion. Cumulative dose distribution is calculated and compared with the prescribed one. The discrepancy, if significant, is repaired using dose compensation technique, in which the cumulative dose distribution is incorporated in adaptive planning for future fractions. Both 3DCRT and IMRT can be used for the boost. One patient with one planning CT and 15 treatment CTs was used in this simulation. Four-field box was used in the plan where CTV was prostate itself. Zero margin from CTV to PTV was chosen to demonstrate the technique. **Results:** Due to the aggressive margins, severe underdose was observed in anterior portion of CTV. The size and magnitude of underdose was reduced substantially with online guidance but was still significant. Both 3DCRT and IMRT boost were able to compensate the dose deficit without any CTV to PTV margins. Dose compensation using 3DCRT caused hot spots in CTV.

Conclusion: We have demonstrated the effectiveness of offline dose compensation technique in IGRT. It complements the online guidance by compensating for other uncertainties that cannot be reduced online. The use of dose compensation allows further margin reduction in IGRT.

SU-EE-A3-03

Incorporate the Imager's Performance Characteristics Into the Design of Prostate IMRT Dose Painting Protocols

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Purpose: There is much interest in using biological and functional imaging to provide guidance in IMRT dose painting. Yet, it is important to incorporate the performance characteristics of these modalities. In this study an example of Ultrasound Tissue Typing (UTT) was utilized to investigate the implications of the imager's performance on the design of a population based prostate dose painting protocol. **Method and Materials:** The performance of an imaging modality can be evaluated via the receiver operating characteristic curve, which is a plot of the imaging modality's sensitivity versus false-positive ratio (1-specificity). As sensitivity increases, more tumors are detected, although specificity worsens, causing more false negatives. The UTT tumor map obtained with a specific sensitivity and specificity setup is fused with the patient's CT image to guide IMRT planning. The optimal escalation dose to the tumor positive region identified by UTT, as well as the safe dose to the identified tumor negative background was obtained by maximizing uncomplicated control, which is a combination of tumor control probability (TCP), and weighted normal tissue complication probability (NTCP). **Results:** A practical dose escalation protocol requires a high specificity imager setup to reduce complications. For tumors at the high-risk stage, with sensitivity at 0.6 and specificity at 0.9, optimal dose to the positive and negative regions are 88.2Gy and 83.6Gy respectively, which resulted in a 25% NTCP reduction compared to that the whole prostate is dose escalated to the same TCP. If the imager becomes more accurate, i.e., sensitivity improves to 0.9 when specificity remains at 0.9, the optimal plan would have a further 10% NTCP decrease with a 2% TCP increase. **Conclusion:** Performance characteristics of an imager as described by sensitivity and specificity has important implications in prostate dose painting, and should be considered in the future design of dose painting protocols.

SU-EE-A3-04

Comparison of Breath-Hold and Free Breathing Approaches for 4DCT Data Acquisition

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Purpose: The objective of this study was to compare two separate respiratory techniques available for four-dimensional computed tomography (4DCT). Regional lung density and spatial displacement of airway tree bifurcations (BPs) were studied and compared between regulated (breath hold) and free breathing techniques. **Method and Materials:** Fifteen normal adult participants were subjected to CT scanning triggered by the lung volume controller system using breath hold and free breathing respiratory techniques. Lung volumes were compared using pneumotachometers (PNT) and respiratory inductance plethysmography. A LabVIEW-based lung volume controller system that allows monitoring/control of lung volumes and provides gating capabilities for CT image acquisition was built. Each subject's slow vital capacity was measured and lung CT images were obtained at two volumes: ~65% vital capacity and the end expiratory phase of tidal breathing (~20% vital capacity). For the free breathing, these represent end inspiration and end expiration. **Results:** The mean difference in location of BPs between inspiration and expiration using breath hold technique [15.3 ± 5.0mm] and free breathing techniques [18.5 ± 7.3mm] were large but similar. Regional mean lung density differences between breath hold and free breathing was insignificant using paired t-test ($p > 0.05$). The BPs spatial uncertainty between breath hold and free breathing, both at end inspiration and end expiration were small: the mean difference in the distance between the carina and any other branch point pair matched was 2.0 mm (±2.0 mm) at end inspiration and 2.8 mm (±2.0 mm) at end expiration. **Conclusion:** Both breath hold and free breathing respiratory techniques significantly (~50%) reduce the uncertainty in branch point localization. In addition, both techniques produce similar regional lung densities. The uncertainty in branch point location with respect to the carina is reduced by 2-3 mm for breath hold compared to free breathing techniques.

SU-EE-A3-05

Robustness of Two 4D Radiotherapy Approaches with Respect to Temporal Irregularity in Organ Motion

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Purpose: Respiratory motion of cancer patients during radiotherapy often lacks spatial and temporal regularity. Delays between motion monitoring and radiation adjustment in motion tracking treatment can cause large deviations between the delivered and the intended dosimetry. We demonstrate the advantage of a motion-pattern-based 4D approach we developed previously with regard to organ motion temporal variation for lung cancer radiotherapy. **Method and Materials:** A 4D CT image set of a lung cancer patient and a moving phantom were studied using 4D treatment planning in the in-house TPS PLUNC, with and without the 4D optimization that is based on *large-deformation diffeomorphic registration* and *index-dose gradient optimization* algorithms. 4D dosimetry refers to the cumulative dose received by anatomical structures in patients with deformable organ motion. The 4D optimization generates static IMRT plans that can be delivered via compensators. The 4D IMRT treatment is compared with non-IMRT motion tracking treatment, with and without tracking delay, for robustness against temporal motion pattern irregularity. The same beam setup, field margin, and dosimetric goal were used by all the plans in the comparison.
Results: The perfect motion tracking technique gave the best CTV 4D DVH. The 4D IMRT performed better than the motion tracking treatment with systematic delays of 0.5 second or larger (motion cycle is 4 seconds). The 4D IMRT yielded better sparing of lung tissue and heart than all the non-IMRT motion tracking treatments. Results on EUD are also presented.
Conclusion: The motion-pattern-based 4D IMRT has the advantages of treatment delivery simplicity and robustness with respect to organ motion temporal irregularity. Compared to non-IMRT motion tracking, it gives better 4D dosimetry for the moving tumor, lung, and heart in treatments of

small-size and large-motion lung tumors having irregular temporal motion pattern.
Conflict of interest: Research is partially supported by Siemens.

SU-EE-A3-06

An Efficient Algorithm for Image-Based Dose Deformation and Accumulation

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Purpose: Construction of the accumulated dose distribution for fractionated radiation delivery in deforming organs based on automated image segmentation and deformable registration of primary and secondary CT datasets. **Method and Materials:** Femur heads, bladder, rectum and prostate were automatically segmented in CT image pairs with 3D deformable triangular surface models. A displacement vector was estimated for each voxel using deformable point-based registration. The vertices of corresponding adapted surface meshes provided corresponding anatomical landmarks, and the deformation between the surfaces was interpolated to every voxel according to a physics-based deformation model. The deformation vector field was applied to warp the primary to the secondary CT, and to warp the dose distributions of the simulated treatments to the original treatment plan. The performance of the registration algorithm to match surfaces was evaluated by warping the bladder and the rectum from one patient to a second patient and measuring surface distances between the warped and target structures. The performance for dose warping was assessed by visually comparing the planned dose in the secondary image to the dose warped from the primary to the secondary image. **Results:** The surface difference between the warped and target bladder (rectum) was 0.65±0.12 mm (1.80±0.97 mm) in 26 patients. The quality of the dose distribution and the variation of dose volume histograms between warped and un-warped plans appeared reasonable on visual inspection. Efficient image resampling techniques enable visual evaluation of the warping result at interactive speed on standard hardware. The surface warp took 2 seconds, plus 5 seconds for warping the 79x60x35 dose grid. **Conclusion:** The work indicates the potential for efficient dose re-planning based on secondary CT imaging during treatment and automated image-processing. Validation work is necessary to assess the effect of different volumetric deformation models on the resulting dose distribution.

Joint Imaging/Therapy Moderated Poster Session
Exhibit Hall 4A - Area 4
Functional Imaging

SU-EE-A4-01

Regional Change in Brain Perfusion, in Irradiated Normal Tissue: Correlation Study Between Perfusion MRI and Spatial Distribution of Radiation Dose Delivered

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Purpose: When irradiating the normal brain, one of the principal causes of complications is damage to the cerebral vasculature, particularly the micro-vasculature. This is of particular concern when treating diseases which are slow-growing or are not malignant. While there is some data relating loss of perfusion to radiation dose in other tissues such as lung, there is very little data for the brain. We intend to determine the relationship between the change due to irradiation in hemodynamic measures, such as relative regional Mean Transit Time (rrMTT) and relative regional Cerebral Blood Volume (rrCBV), and the radiation dose delivered to the normal brain tissue. **Method and Materials:** We acquired data in the form of perfusion weighted images (PWI) for two patients. We used a 3.0 T magnet at the Seaman Family MRI Centre at the Foothills Medical Centre and a single-shot echo-planar imaging (EPI) sequence following the injection of a paramagnetic contrast agent (Gd-DTPA-Magnevist; Berlex, Wayne, NJ). These images have been processed to yield rrCBV and rrMTT. The patients had previously been treated with surgery, but had received no chemotherapy. **Results:** Our preliminary results show that with a follow-up time of 4 months after receiving approximately 5000 cGy/25 fractions, in normal brain tissue the rrMTT is reduced by approximately 2% (1.8 ± 0.5) and the rrCBV is reduced by almost 12% (11.8 ± 2.2). The tumor showed reductions in both rrMTT (1.2 ± 1.5)% and rrCBV (19.9 ± 3.5)%. It is expected that these changes will increase with longer term follow-up. **Conclusion:** Perfusion Weighted MR Imaging can be used to assess the change in hemodynamic measures in the normal brain tissue after radiotherapy.

SU-EE-A4-02

Quantitative Assessment of Tumor Heterogeneity Using Spatial Statistical Methods

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Purpose: To quantitatively define and compare tumor heterogeneity via spatial statistical analyses of PET images for assessment of tumor response to treatment. **Method and Materials:** Canine tumor images, acquired through 65 minute dynamic ^{18}F-thymidine PET scans pre and three, six days post treatment, displayed varying heterogeneous uptake and tracer concentration in specific regions. CT/PET scans co-registered over multiple scan days provided single day slices averaged after uptake (16-65 min) and cropped to the tumor area for each imaging stage. Images were tested for correlation and clustering using global Moran I and local G spatial statistics. **Results:** For each image, global I(d) statistics gave values greater than 0.5 (indicating positive spatial correlation) within a distance of 10 mm before going to zero (no correlation) at longer distances. The rate at which I(d) went to zero for each image differed. Six days post treatment decreased to zero most rapidly, three days post decreased most slowly, and the pre scan between these two rates. Local G statistics revealed the position and redistribution of high Z(G) value cluster regions in the pre and post six day scans over various distances. The post three day image revealed uniform Z(G) values over the majority of the tumor region. **Conclusion:** Results showed that global Moran I(d) and local G statistics are useful tools in assessment of tumor heterogeneity. Mean correlation lengths and cluster re-distribution can be obtained through I and G statistics. Greater I(d) values and a slower I(d) rate to zero for three days post treatment implied that a longer correlation length was present after radiotherapy as FLT uptake and proliferation increased in uniformity. Shorter correlation lengths six days post treatment indicated uptake and proliferation heterogeneities returning larger than prior to treatment. Local G statistics visually displayed how regions of proliferation clusters were re-distributed throughout treatment.

SU-EE-A4-03

Validation of GATE Monte Carlo Simulations of the Noise Equivalent Count Rate and Image Quailty for the GE Discovery LS PET Scanner

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Purpose: The needs of radiation therapy treatment planning impose higher demands on PET/CT imaging accuracy. The recently developed GATE (Geant4 Application for Tomographic Emission) Monte Carlo package, provides the possibility to model accurately the factors contributing to decreased PET resolution and image degradation. The purpose of this study is to test GATE's ability to predict time curves and image quality (IQ) for the GE Discovery LS/Advance PET scanner. **Method and Materials:** Our 3D PET simulation model of the GE Discovery LS scanner and phantoms follows both the vendor's and NEMA's specifications and was previously validated for the PET scatter fraction and sensitivity tests. Simulations with this model were performed for the count rate and IQ NEMA-2001 tests as a function of activity concentration. The Software for Tomographic Image Reconstruction (STIR) package was used to reconstruct the simulated data which was then compared to experiment. **Results:** Our simulations correctly predict the shape and magnitude of the true, scatter, random, and NEC rates. The simulated peak true and NEC rates are both within 3 kBq/cc of the measured data. Scatter and random rejection in the Monte Carlo data dramatically improved the agreement between measured and simulated contrast ratios. The cold sphere contrast ratio is within 9% of the measured data when the scatter and random coincidences were rejected. Larger discrepancies for the hot sphere

contrast are currently observed and investigated. **Conclusion:** Monte Carlo simulation of PET images and the corresponding NEC rates can aid in improving PET image quality. The ability to model the features of PET scanners accurately makes GATE a potentially useful tool in improving PET's performance, which is necessary for its effective use in radiation treatment planning

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SU-EE-A4-04

Compartment Modeling Analysis of Cu-ATSM Dynamic PET Images

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Purpose: Copper labeled diacetyl-bis(N4-methylthiosemicarbazone) (Cu-ATSM) has been reported to selectively bind to hypoxic tumor cells. This makes Cu-ATSM PET a promising modality to image tumor hypoxia. However, intravascular Cu-ATSM that is not related to hypoxia, can also contribute to the PET signal. The purpose of this study is to use compartment modeling analysis to separate tumor tissue time-activity Cu-ATSM signal into intravascular and extravascular components. **Method and Materials:** A dynamic Cu-ATSM PET scanning was performed on tumor-bearing (R3230 mammary adenocarcinoma) rats. The Cu-ATSM concentration is separated into an intravascular concentration (C_p) with vascular volume fraction (v_p) and extravascular concentration (C_e). The transfer between the intra- and extra-vascular compartments is described by rate constant k. The time activity data of Cu-ATSM were fed into the compartment model. After non-linear least square (NLLS) fitting of the model, tumor signal was separated into intravascular and extravascular components. Vascular volume fraction v_p and rate constant k were also obtained from the fitting. **Results:** The time courses of the intravascular and extravascular Cu-ATSM signals were obtained from the NLLS fitting and are shown in figure 1 in the supporting document. The fitted Cu-ATSM uptake signals match closely with the measured results. The vascular volume fraction obtained from the fitting for three tumors was 2.4%, 2.3% and 2.9%, and the transfer rate from blood to tissue was 0.045, 0.043, and 0.047 (1/minute), respectively. **Conclusion:** Compartment modeling analysis can effectively remove the intravascular Cu-ATSM signal from the overall tissue signals, reflecting more accurately the tissue uptake and tumor hypoxia. Tumor vascular volume fraction and Cu-ATSM transfer rate constant can be obtained from the compartment modeling analysis.

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SU-EE-A4-05

Individual Target Volume Definition in NSCLC Using PET

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Purpose: To determine whether quantitatively segmented PET images could be used to identify the volume containing a tumor and its total motion. If possible, PET could provide individualized internal target volumes (ITV) in lung cancer. **Method and Materials:** A physiological phantom containing background level of Na-22 was used. Two spheres filled with 0.5 mCi/ml of Na-22 were used to simulate tumors; each was oscillated within one lung of the phantom with 4 preset motion extents in S/I, A/P, and M/L directions. PET and CT imaging were performed on an integrated PET/CT scanner. A CT-based GTV was generated using a threshold of –850 HU. A population-based margin of 15 mm, reflecting both motion and set-up uncertainties, was added to generate a CT-based PTV. A PET-based ITV was defined using a threshold of three standard deviations above normal lung background. A set-up margin of 7.5 mm was added to PET-based ITVs to create PTVs. Image-based PTVs were compared to ideal PTVs. Clinical validation of this methodology was performed on 7 patients with parenchymal lung lesions with the addition of digital fluoroscopy. 18-FDG was used for patient PET scanning. **Results:** For the phantom study, PET-based PTVs were closer to the ideal PTV than those based on CT. While the PET-based PTVs were approximately half the size of the CT-based PTVs, in no case would the PET-based PTVs have resulted in geographical miss. For majority of the patients, PET accurately predicted or slightly over-predicted the tumor motion extents compared to fluoroscopy; differences were within 2 voxels. **Conclusion:** Based on the phantom study and initial clinical validation, we have found that quantitatively segmented PET images can provide an accurate individualized ITV that correlates with a tumor and its motion. **Conflict of Interest:** Research was supported by NCI Canada with funds from Ontario Cancer Society.

SU-EE-A4-06

Longitudinal Correlations in a Small-Animal PET Studies

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Purpose: One area of interest in the rapidly developing field of small-animal imaging is preclinical evaluations of cancer therapeutics. It is clear that longitudinal imaging studies reduce the number of animals necessary for such evaluations by following a single cohort over multiple timepoints. However, there is additional benefit to longitudinal data for comparisons between timepoints. Of particular interest in preclinical studies are comparisons between the disease status at the onset of treatment and later timepoints after treatment has been completed. Positive correlations between timepoints add statistical power to tests of differences. In this work, we investigate correlations in quantitative features across timepoints in small-animal positron emission tomography (PET) images of a mouse model of breast cancer. **Method and Materials:** We investigate a mammary intraepithelial neoplasia outgrowth (MIN-O) model in FVB mice. Transplant development in these animals is similar to the neoplastic progression of breast carcinoma from preinvasive ductal carcinoma in situ to invasive carcinoma in humans. A cohort of mice were imaged 5 times on a dedicated small-animal PET scanner after injection of a commonly used radiotracer (FDG). After reconstruction, quantitative features such as functionally active volume, maximum uptake and total uptake were computed as markers of development. **Results:** Quantitative features document development of disease in these animals over time. Positive person correlation coefficients ranging over 0.3 and > 0.9 have been observed between timepoints for the extracted features. This leads to substantial gains in statistical power. **Conclusion:** Features extracted from volumetric PET images in the MIN-O mouse model correspond with development of disease. Because of the variability in disease progression and proliferation between lesions, there is a considerable statistical advantage to longitudinal studies. Correlations between timepoints measured for this work lead to quantifiable gains in statistical power.

Therapy Moderated Poster Session
Exhibit Hall 4E - Area 1
IMRT Clinical Applications 2

SU-EE-A1-01

Comparison of Monte Carlo and Convolution/Superposition Calculation Methods: Quantification of the Dose Prediction Errors Arising From Tissue Heterogeneities

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Purpose: To investigate the extent of the dose prediction error (DPE) due to tissue heterogeneities in superposition/convolution (SC) based dose calculations by comparisons with Monte Carlo (MC) calculations for head-and-neck IMRT treatment plans. **Method and Materials:** A retrospective investigation is performed for ten Head-and-Neck IMRT patients. Dose calculations are performed with SC and MC algorithms. For both algorithms, the intensity modulation generated by the dynamic multi-leaf collimator (DMLC) is incorporated into the dose calculation via a transmission matrix generated by determining the ratio of incident and transmitted energy fluence through the DMLC using a MC algorithm. Plans were compared based upon the criteria used during the IMRT optimization: GTV D_{98}, CTV D_{95}, Nodal volume D_{90}, Cord D_{02}, and Parotid D_{50}. As the same transmission matrix is used for both methods and the SC and MC algorithms subsequent dose differences are attributed to handling of the tissue heterogeneities by the SC algorithm. **Results:** The GTV D_{98} and CTV D_{95} local doses agree within ±3.2% for the SC and MC calculations. Differences are within ±1.8% for the D_{90} of the nodal target volume. The cord and the brainstem D_{02} doses differ by $<\pm 3.5\%$ and $<\pm 2.5\%$ of the local dose respectively. The Parotid D_{50} shows the greatest variations, with local

differences up to 5.8%. The observed deviations do not show systematic under- or over-estimate of the dose by SC. **Conclusion:** When identical transmission matrices are used, the DPE of the SC method, using the MC method as a references, is <±3.2% for the target structures. For the critical structures, DPEs as high as 6% of the local dose were observed, which corresponds to <3% if normalized to the prescription dose. (Supported by NIH-1R01CA98524)

SU-EE-A1-02

Feasibility Study of Helical Tomotherapy for Total Body and Total Marrow Irradiation

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Purpose: Total body radiation (TBI) has been used for many years as a pre-conditioning agent before bone marrow transplantation. Many side effects still plague its use. To assess the feasibility of using Helical Tomotherapy, we investigated various parameters and treatment techniques. **Method and Materials:** We studied variations in pitch, field width, and modulation on total body and total marrow helical tomotherapy treatments. We varied these parameters to provide a uniform dose along with a treatment times similar to conventional TBI (15-30 min.). We also investigated using limited total body mega-voltage CT (MVCT) scanning rather than total body MVCT scanning to shorten the time per treatment fraction. Thermoluminescent detectors (TLDs) were placed inside a Rando phantom and we measured dose at seven anatomical sites including the lungs. Whole body MVCT and limited MVCT (head, chest, and pelvis) scanning were used for 3-D set up verification. **Results:** TBI simulation showed homogeneous dose coverage to the whole body. Doses to the sensitive organs were reduced by 35-70 % of the target dose. In the TMI study, dose was mainly conformal to the bone marrow only. TBI and TMI treatment delivery time was reduced (by 50%) by increasing the field width from 2.5 cm to 5.0 cm in the inferior-superior direction**.** TLD measurements on Rando showed accurate dose delivery to the target and critical organs. A limited MVCT reduced the target localization time significantly compared to whole body MVCT. **Conclusion:** This study showed that Helical Tomotherapy can deliver uniform dose to the total body and total marrow by a judicious selection of pitch, modulation, and field size. A limited MVCT also can be used in place of whole body MVCT. Details of this investigation will be presented. **Conflict of Interest:** The authors associated with TomoTherapy Inc. have a financial interest in that company.

SU-EE-A1-03

Inhomogeneity Correction in IMRT Beamlets: Significance in Lung Treatments

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Introduction: To examine the efficacy and accuracy of pencil beam (PB) and collapsed cone convolution (CC) algorithms that are commonly used in IMRT optimization and dose calculation. The magnitude of error is also estimated with measurement for small IMRT beamlets. **Method and Materials:** The CT scan of a specially designed lung phantom was used in the dose calculations, with and without inhomogeneity correction, for both algorithms. The inhomogeneity correction factor; CF=Di/Dh, where Di and Dh are the doses at the same depth with and without inhomogeneity, respectively, was calculated for 6 MV and 15 MV beams. Small volume ion chamber and Gafchromic films were used for the measurement, with varying depths and field sizes ranging from 1x1 - 10x10 cm^2. Dosimetry was also performed with various other detectors to study the accuracy of the dose algorithms in homogenous water phantom. **Results:** Small volume chambers and diodes provided similar results in homogenous phantom for small fields. The PB algorithm is relatively insensitive to field size whereas collapsed cone is field size dependent. The CF with PB and CC has wide variations (up to 60%) for 6 and 15 MV beams for small fields. As field size increases, the difference decreases. For 10x10 cm^2 fields the two algorithms differ by only 4-5%. CF is dependent on the distance of inhomogeneity, field size and beam energy, and the effect is more pronounced for 6 MV than for 15 MV beams. Both ion chamber and Gafchromic films are in better agreement with CC calculation. **Conclusion:** Significant differences between PB, CC and measurements are noted that disappear for large fields, however, CC should be preferred for IMRT. Faster optimization and calculation hardware should be implemented since CC takes 10 times longer time than PB calculation. Special care is needed for validations of these complex algorithms.

SU-EE-A1-04

Integrated Complementary IMRT Combined with Image-Guided HDR Brachytherapy for Cancers of the Uterine Cervix

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Purpose: Conventional HDR (CHDR) brachytherapy for cervical cancers often fails to cover the entire gross tumor volume (GTV). CT/MRI-based 3-D planning allows optimization of dwell times for improved target coverage, but often at the cost of substantially higher doses to organs at risk (OARs). In the present study, we integrate image-guided HDR brachytherapy with concomitant complementary IMRT to boost target coverage and maintain low doses to OARs. **Method and Materials:** Treatment planning CT and MRI images of 6 patients were acquired with CT/MRI-compatible carbon-fiber applicator. HDR plans were obtained by modifying CHDR plans to keep bladder and rectum dose below 80%. Based on these HDR plans, IMRT plans were subsequently optimized to complement the dose coverage of GTV with 3-mm margin (GTV^+) and the uterus. To prevent anatomical deformation, IMRT plans were to be delivered immediately following image-guided HDR treatment with applicator in place. $V_{95\%}$ (Target volume receiving 95% prescription dose) and D_2 (minimum dose in 2.0-cm^3 OAR volume receiving the highest dose) were used to compare IMRT-HDR technique with CHDR and HDR optimized for target coverage (OHDR). **Results:** The MRT-HDR technique substantially improved target coverage while maintaining bladder and rectum doses at acceptable low level. For the six patients, $V_{95\%}$ for GTV^+ and the uterus improved from the average of 56.8% and 51.4% in CHDR to 92.5% and 95.3% in IMRT-HDR, respectively. Average D_2 doses to bladder and rectum were 88.7% and 65.2% for CHDR and 72.4% and 71.4% for IMRT-HDR. In contrast, OHDR improved target coverage, but D_2 doses to bladder (>119%) and rectum (87.3% to > 200%) were unacceptably high. **Conclusion:** Integrated complementary IMRT combined with image-guide HDR significantly improves dose coverage to the targets while maintaining low doses to OARs. It is dosimetrically and logistically feasible to clinically implement this technique for potentially improved outcome.

SU-EE-A1-05

Intensity Modulated Radiation Therapy (IMRT) as An Alternative to Adjuvant High Dose Rate (HDR) Brachytherapy in Endometrial Cancer Patients

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Purpose: To evaluate the role of IMRT as an alternative to HDR brachytherapy for the adjuvant treatment of endometrial cancer patients following surgery. **Method and Materials:** The CT scans of five patients previously treated with adjuvant HDR were used in this study. All patients were scanned with a vaginal cylinder in place, and HDR planning was performed using the BrachyVision (Varian Medical Systems) software. In all cases, a dose of 700 cGy/fraction was prescribed at a distance of 0.5 cm from the cylinder surface. The same planning CT scans were then used for IMRT planning (Eclipse, Varian Medical Systems). In this paradigm, the vaginal cylinder is a component of a hypothetical immobilization system that would be indexed to the linac treatment table. The goal of IMRT planning was to deliver the prescription dose to the clinical target volume (CTV) while minimizing the volume of rectum and bladder irradiated. Dose volume histograms (DVHs) of the bladder, rectum and CTV were recorded and compared for both HDR and IMRT plans. **Results:** The mean bladder doses (as a percentage of the prescription dose) were 31.8% and 32.2% ($p = 0.93$) for the HDR and IMRT plans, respectively. However, in 4 of the 5 plans, IMRT produced lower maximum bladder doses compared to HDR (averages: IMRT = 99.1% vs. HDR = 158.4%). IMRT plans also resulted in lower mean rectal doses (21.6%) than HDR plans (30.9%) ($p = 0.01$). Moreover, the maximum rectal doses were lower in all IMRT plans compared to the HDR plans (95.1% vs. 165.8%). On average, the minimum dose to CTV was slightly higher using IMRT (97.8% vs. 95.5%).

Conclusion: These results suggest than when used in conjunction with a suitable immobilization system, IMRT may provide an alternative to HDR brachytherapy in women with endometrial cancer following hysterectomy.

SU-EE-A1-06

Investigation of MR Image Distortion for Radiotherapy Treatment Planning of Prostate Cancer

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Purpose: To implement MRI based treatment planning clinically for prostate cancer, the machine generated geometrical distortions on MR images must be investigated to ensure the accuracy of dose calculation and treatment delivery. **Method and Materials:** The MR system used for this study was a 0.23 Tesla open scanner (Philips Medical System, Cleveland, OH) operating clinically as an MR simulator. Based on the fact that there was no observable patient induced MR image artifact with 0.2 T low magnetic fields, the patient induced geometrical distortions were negligible for our MR unit and the machine induced geometrical distortions could be detected, studied and corrected accurately. A distortion evaluation phantom (F18) was employed to measure the distortions after a gradient distortion correction (GDC) software was installed to post-process the images and a point-by-point correction method was then developed to remove the residual distortion based on precise measurements. **Results:** With our routine clinical 3-dimensinal fast spin echo sequences, our work shows that there are no patient induced distortions detected and the machine specific geometrical distortions can be quantified and corrected first by the GDC post-processing software and then by the point by point correction technique. The residual distortions after the corrections are reduced from the original > 2 cm to < 3 mm in the external contour determination for patients with large lateral dimensions. An effective FOV has been established, which can be used clinically to set up patient selection criteria for MR based treatment planning. **Conclusion:** MR geometrical distortions on MR scanners can be corrected and, with the GDC post-processing and our point by point correction technique, 2% to 5% improvement in dose accuracy can be expected in the treatment planning for prostate cancer.

General Poster Discussion
Exhibit Hall 4A
Educational

SU-FF-E-01

A Streamlined Syllabus for Training of Radiation Therapy Professionals On Linac Operations

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Purpose: To define a syllabus for the education and periodic re-training of radiation therapists and other professionals operating a linear accelerator (linac) on issues related to safety, routine operations, and emergency procedures. **Method and Materials:** An extensive review of manufacturer recommendations and published literature regarding linac safety and operational issues has enabled the compilation of a streamlined syllabus. The course material is geared toward rapid and effective training of radiation therapists and other individuals charged with operating a linear accelerator either during treatment delivery or while performing commissioning or periodic quality assurance measurements. The training material is meant to be delivered on a rotating schedule such that re-training of personnel is accomplished. The course material itself is designed to be delivered by a Chief Therapist, Linac Engineer, and/or Medical Physics staff. **Results**: A syllabus including course material to be delivered monthly, semi-annually, and annually has been developed. The target audience includes radiation therapists, service engineers, and physicists/dosimetrists involved in the operation of a linac. The course material includes separate components catered to the interest and knowledge requirement for different trainees. For example, concise protocols to be followed for morning warm-up are presented semi-annually to the therapists in charge of opening the department. All treating therapists are exposed to pertinent safety procedures during monthly inservices developed such that a complete cadre of safety related issues is covered twice per year. More extensive annual refresher courses are also defined, along with measurable indicators that can be used to document understanding of the procedures. **Conclusion:** Quality assurance requirements mandated by most jurisdictions dictate frequent training of appropriate personnel pertaining to linac safety including coverage of routine operations and emergency procedures. This work standardizes a syllabus that can be used to satisfy these training requirements. Monthly, semi-annual, and annual training programs are included.

SU-FF-E-02

Modern Digital Seminar/Teaching/ Conference Room

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Orlando Ortiz M.D.

Purpose: Digital Teaching/Seminar/Conference Room for the modern era. **Method and Materials:** Learn about and become familiar with the resources available to set up a digital teaching/seminar/conference room **Results:** 1. Assess the technologic innovations in hardware, software and network design and the impact to the conference room. 2. Understand ways to optimize your images for visual display with respect to luminance, gray scale imaging, contrast and distortion. 3. Review the technologies available for the storage, projection, and display of a presentation. **Conclusion:** Reviewed how the teaching/seminar / conference room has evolved in parallel with the changes from an analog to a digital environment.

SU-FF-E-03

RadSim, a Program to Simulate Individual Radiation Interactions for Teaching Purposes

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Purpose: To develop a computer program to simulate individual particle interactions in a visual way, as a teaching aid in radiotherapy physics. **Method and Materials:** A program, RadSim, was developed using the RealBasic software development environment. A Graphical User Interface allows users to select individual interactions to be simulated for photons, electrons and positrons in the energy range encompassing radiation oncology (1 keV – several hundred MeV). The program is designed to operate in two modes. In the Manual mode a single interaction is performed. In the Simulated mode the user can run a short Monte Carlo simulation for a small number of particles. In the latter mode statistics on the interaction variables are displayed graphically. The program is made available in versions for the Windows, Linux and Mac operating systems, via free download from a website. **Results:** The user can simulate the following types of interactions: for photons: Compton scatter, photo-electric effect with characteristic x-rays, Rayleigh scattering and pair-production, for electrons: inelastic nuclear scattering with Bremsstrahlung production, electron-electron scattering, for positrons: Bhabha scattering and annihilation. The Manual mode allows visual evaluation of kinematic equations. The user can initialize any combination of a minimally required set of interaction variables and the program evaluates the remaining variables, and displays the interaction visually showing incoming and outgoing particles. In the Simulated mode, the user can only change the kinetic variables of the initial particle. The final state of all particles involved is generated from a Monte Carlo simulation. The user defines the number of particles used in the simulation and frequency distributions are displayed during the simulation so that the user can watch the distributions grow. **Conclusion:** The program RadSim enables virtual radiation experiments in the classroom and for self-learning and is found to be a useful addition to textbook teaching.

SU-FF-E-04

Using the Internet for Real-Time Education and Knowledge Exchange in Medical Physics

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Purpose: This work provides an update to the ongoing project of Remote Real-Time Learning. (http://www.neteinfach.com/rrtl/index.htm). The goal of the project is to promote the use of Internet to provide classroom style real-time interactive education in Medical Physics. **Method and Materials:** This project was started 3 years ago as a collaboration between

the Department of Medical Physics at the Toronto-Sunnybrook Regional Cancer Centre in Canada and the Department of Radiology at the University of Malaya in Malaysia. A class of Medical Physics graduate students at the University of Malaya attended lectures provided by lecturers in Toronto, using the Internet as the main tool of communication.
As part of the study, the different methods that can be used to provide real-time interactive remote education were explored, and various topics including traditional classroom lectures as well as hands-on workshops were also delivered. **Results:** Based on our experience, a reasonably stable methodology has been established. This methodology allows a fairly smooth set-up and conduction of the lectures, at an insignificant cost, while offering flexible convenience to the lecturers as well as the students, despite the widely different time zones. **Conclusion:** The current plan is to expand the process to allow students at multiple sites of the world to attend the online lectures at the same time. Our project welcomes the participation of both lecturers and students who are interested in taking advantage of the advance of the Internet to promote greater accessibility of quality education in the field.

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General Poster Discussion
Exhibit Hall 4A
Imaging

SU-FF-I-01
A New Nipple Detection Algorithm Based On Curvature
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Purpose: Nipple is an important anatomical feature for mammogram registration and bilateral asymmetry analysis. We will investigate a new nipple detection algorithm based on curvature analysis. **Method and Materials:** Nipple extends outward and changes the curvature on the breast skin-line. Curvature analysis will be proposed to locate the nipple in this study. The breast skin-line is first estimated by using a dependency approach. The skin-line is then smoothed by average-smoothing. Curvature is calculated along the skin-line boundary. The intersection point between the nipple and the skin-line is characterized by a large negative curvature. The nipple is thus located between two positions having the largest negative curvature values. The final nipple position is computed as the average of these two positions. We have tested our algorithm on 26 mammograms with the extended nipple from the MIAS database. **Results:** The proposed curvature-based algorithm correctly detects the nipple position in each image. **Conclusion:** Our proposed nipple detection method is based on curvature analysis and performs well on mammograms with the outward nipples. The further work will be quantitative evaluation of the algorithm.

SU-FF-I-02
Automatic Detection and Sizing of Metastatic Brain Tumors Using 3D Template Matching
R Ambrosini*[1], P Wang[1], J Victor[1], N Sobe[2], W O'Dell[1], (1) University of Rochester, Rochester, NY, (2) University of Pittsburgh, Pittsburgh, PA

Purpose: The prognosis of patients with brain metastases is generally poor, but is improved with early detection and treatment with stereotactic radiosurgery as performed routinely at our institution. To achieve the earliest possible detection of subclinical lesions requires frequent screenings and use of high resolution volumetric imaging. This results in an ever-increasing workload for the radiologist, predisposing an increased tendency for reading error, especially for small nodules. We have developed a novel small tumor detection algorithm based on 3D template matching that also quantifies nodule size and hence growth between scanning sessions. **Method and Materials:** Post-contrast, coronal, SPGR, T1-weighted MRI datasets (voxel size 0.43x0.43x2.5 mm) were acquired. Autoextraction of bone and other non-brain tissue from the brain volumes was accomplished using morphological operations. Spherical tumor appearance models were created to match the expected geometry of the small tumors of interest and accounting for offsets due to the cut of MRI sampling planes. A 3D normalized cross-correlation coefficient (NCCC) between the brain volume and spherical templates was calculated using a fast frequency domain algorithm. Volumes of nodules were determined using both voxel-based measurements and by modeling each as an ellipsoid. **Results:** Spherical templates were optimized for values of the radius, padding, and thresholding parameters. The data collected shows that a 100% tumor detection rate can be achieved with a true positive to false positive ratio of 4.5 with the cerebellum cropped out and 1.25 with the cerebellum present. Growth of the nodules over 11 months was automatically quantified, as well as detection of 1 new lesion. **Conclusion:** Our results demonstrate that the 3D template-matching method can be an effective, fast and accurate tool for automated detection of tumors in brain MRIs. Strategic integration of results from multiple templates can further minimize the false positive rate while maintaining a 100% detection rate.

SU-FF-I-03
Evaluation of Computer Aided Diagnosis On Thin-Slice Pulmonary CT Images
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Purpose: Pulmonary stereotactic radiation therapy achieves a >90% local control rate for small tumors (<30mm); motivating early detection of small lung nodules. With the increasing image resolution afforded by multi-slice CT scanners, radiologists can discern more easily these very small lung nodules. However, to overcome the challenge of image overload, assistance from lung CAD systems becomes a necessity. The purpose of this work is to evaluate the performance of our lung CAD algorithm on low-dose, thin-slice CT images from the Early Lung Cancer Action Program (ELCAP) database. **Method and Materials:** Our CAD algorithm models lung nodules as spheres (a modification of the 3D template-matching method presented in AAPM'03) and searched for structures similar to the templates throughout the whole lung volume. This approach eliminates the need for segmentation of blood vessel-nodule complex and is insensitive to noise and low-contrast of some nodules. In the extraction of lung volume, a watershed transform was applied to separate left and right lungs when necessary. A 3D spherical structure element was used to smooth out the surface of both lungs in order to incorporate pleural nodules. An improved padding scheme was adapted on the templates to make the detection capacity of templates more isotropic. A test dataset was used, consisting of 55 central contiguous slices (voxel size: $0.57\times0.57\times1.25mm^3$) from a particularly challenging subject in the ELCAP database. 41 nodules were identified by an experienced radiologist from our institution. **Results:** 37 out of 41 nodules were detected by our CAD algorithm, a sensitivity of 90.2%. Among them, 28 out of 32 nodules with diameter <3mm were detected. The smallest detected nodule had a diameter of only ~3 pixels (1.7mm) and a volume of ~17 voxels. **Conclusion:** Our CAD method is capable of detecting with high sensitivity very small lung nodules in low-dose thin-slice chest CT.

SU-FF-I-04
A Comparison of Two Genetic Algorithms for Feature Selection in the Detection of Breast Cancers
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Purpose: Features are usually extracted for separating breast cancers from normal areas in computer-aided detection (CAD) on screening mammograms. Feature selection is an important step to select a best subset for achieving the best detection of breast cancers. **Method and Materials:** The study is to evaluate two genetic algorithms for feature selection for breast cancer detection. Normal regions of 512×512 pixels were extracted from normal mammograms, and abnormal regions of 512×512 pixels depicting breast cancers were extracted from cancer cases. A total of 86 features were extracted from each region, including 18 features from curvilinear structure analysis, 16 from texture analysis, 32 from Gabor filtering, and 20 from wavelet decomposition. Two genetic algorithms (GA), simple GA (SGA) and CHC, were used to select a subset of features. A linear discriminant analysis (LDA) was used to classify cancer regions

from normal regions with the selected feature subset. The performance was evaluated by using the Receiver Operating Characteristic (ROC) analysis. We have tested these two feature selection methods on a dataset of 296 normal regions and 164 cancer regions (including 53 masses, 56 spiculated lesions and 55 microcalcifications) extracted from mammograms selected from DDSM database. **Results:** The overall ROC performance of SGA and LDA is A_z=0.90, with comparison to A_z=0.93 of CHC and LDA. **Conclusion:** We compared two genetic algorithms for feature selection. CHC performed better than SGA for the detection of breast cancers in the current study.

SU-FF-I-05

A Bench-Top Megavoltage CT (MVCT) Scanner with Cadmium Tungstate-Photodiode Detectors

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Purpose: To design, fabricate and test the data acquisition timing control, precision rotary stage control, and an analog data multiplexer unit for a prototype megavoltage computed tomography (MVCT) detector. To measure the basic detector characteristics such as linearity with dose rate, the pre-sampled modulation transfer function (*MTF*), the noise power spectrum (*NPS*) and the detective quantum efficiency (*DQE*). **Method and Materials:** The 80-element prototype detector array is made with $CdWO_4$ (element size 0.275 x 0.8 x 1 cm^3) scintillators and photodiodes placed on an arc with a radius of 110 cm. In addition to designing and fabricating an in-house data acquisition system (front-end integrators, data multiplexer unit, and timing control), a precision rotary stage and its control are added to create a third generation MVCT scanner. The data acquisition is synchronized with radiation pulses from a linear accelerator. The response of the detector as a function of dose rate was studied by varying the source to detector distance. A narrow slit beam, at five locations, was used to measure the pre-sampled *MTF*. The detector signal in open beam was measured for a number of radiation pulses to use the periodogram method for *NPS* estimation. Using the measured *MTF*, *NPS*, and the photon fluence impinging on the detector, the *DQE* was calculated. **Results:** Detector response is linear as a function of dose rate, however, shows a non-linear component while measuring the attenuation by solid water due to the poly-energetic spectrum. Therefore, beam-hardening correction is necessary before MVCT image reconstruction. The *MTF* at the Nyquist frequency (0.16 mm^{-1}) is approximately 0.48. The zero-frequency *DQE* in 6 MV beam at 21% is higher than any experimental MVCT detector. **Conclusion:** The basic performance of the prototype detector was found to be satisfactory for producing reasonable low contrast resolution in MVCT images with low dose.

SU-FF-I-06

Determination of Optimal KV for Imaging Iodine and Bone in Computed Tomography

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Purpose: To determine the kV that will yield optimal contrast to noise ratio (CNR) at a constant patient dose for iodine/ soft tissue and bone/ soft tissue contrast in head and small body studies. **Method and Materials:** A head phantom containing water equivalent material and a bone ring to simulate the skull (for head studies) was used to obtain the data. To measure the contrast of iodine to water and bone to water, cylindrical plugs were inserted into the phantom: two plugs contained different dilutions of iodine contrast (Omnipauqe 300mgI/ml), one contained bone equivalent material, and one contained water. This phantom was scanned at kV values ranging from 80 to 140 kV. The contrast was measured as the difference in CT number between the iodine and bone plugs and the water plug. The noise measurements were taken from the water plug. Noise was determined at constant dose (CTDI w), so that the mAs was increased as the kV decreased. Both image noise and image contrast increased as the kV decreased. The relevant parameter for determining optimal kV is the contrast to noise ratio (CNR) at a constant dose as a function of kV. **Results:** The optimal kV, within the range of 80 to 140 kV, for the imaging of both iodine and bone is 80 kV. Limitations to this kV selection include the possible presence of increased artifacts in bone imaging, and CT scanner limitations in mAs that might not allow low kV with an adequate level of image noise. **Conclusion:** The common use of 120 to 140 kV in CT scanning may not be optimal for many studies whose primarily objective is the discernment of iodine or bone contrast, such as in brain perfusion studies. The use of lower kV settings may be advantageous in these cases.

SU-FF-I-07

Respiratory Correlated CT: Acceptance and Clinical Introduction

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Purpose: Respiratory correlated CT (RC-CT) has the potential to enable individual margins and prevent geometrical miss in radiotherapy for lung cancer patients. The objective of this study was to develop a procedure for acceptance and clinical introduction of RC-CT. **Method and Materials:** RC-CT was performed with a modified Siemens Sensation 10 and Biograph PET/CT with extremely low pitch (0.1) in combination with a respiratory signal obtained by a pressure sensor in a chest belt. Two phantoms were used for acceptance: Phantom 1: A ventilator (12 and 20bpm) and balloon, on which metal markers and the chest belt were positioned. This phantom was used to test the accuracy of the system. Phantom 2: A sphere moving 34mm(A-P), 6mm(L-R) and 34mm(Cr-Ca) at 18bpm was used to evaluate distortion. Clinical introduction: In 16 NSCLC RT patients an RC-CT was performed and tumor movement was measured. The volume within which the visible tumor moved(IGTV), was delineated and projected onto the regular CT/PET used for treatment planning. **Results:** Phantom 1: Correlation between reconstructed and true displacement of the markers with respiration was excellent (R=.992 p<.001 for the vector movement). The relation between true and reconstructed displacement was not significantly different from identity. Phantom 2: The distortion was minimal, in each of the ten respiration phases the sphere volume (65cm^3) was accurately reconstructed within 4cm^3. Patients: In all patients, RC-CT could be successfully performed without coaching. The duration of the scan was always less than 90 seconds, with the whole procedure completed within 10 minutes. An RC-CT delivered an estimated dose of 20cGy (CTDI). Mean and range of movement was 2.5±1.6,0-6mm(A-P), 1.4±1.7,0-5mm(L-R) and 4.4±4.5,0-15mm(Cr-Ca). **Conclusion:** A procedure for acceptance and clinical introduction of RC-CT has been developed. The results of the tested RC-CT system were satisfactory and the system is now in clinical use.

SU-FF-I-08

What Is the Best Way of Measuring An Image Quality Index From CT Data?

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Purpose: To investigate how tissue contrast and noise correlate with the size of patients undergoing chest CT examinations. **Method and Materials:** We used 572 chest CT examinations obtained with a standard protocol for subjects participating in a lung cancer-screening project. Measurements were made of the mean CT number (HU), and corresponding noise level (standard deviation), in liver and blood in the descending aorta. Data on patient size included the patient weight (kg), body dimensions (Anterior-Posterior [AP] and lateral [L]), as well as the body mass index (BMI) obtained as the ratio of the body weight (kg) divided by the square of the patient height (m). **Results:** Visual inspection of the CT images shows the expected increase in image noise with increasing patient size. Mean CT numbers for liver showed a modest decrease with increasing patient weight (r^2 = 0.18), whereas blood showed no correlation with patient size (r^2 < 0.01). There was good correlation between noise and patient mass for the liver (r^2 = 0.65) and for blood (r^2 = 0.54). Compared to noise alone, contrast to noise ratios for both tissues showed a reduced correlation with patient mass. The correlation between noise and patient size was similar for body weight and three measures of patient size (i.e., (AP + L), (AP x L)$^{0.5}$, and (ln[AP x L]$^{0.5}$), but was significantly poorer with BMI. **Conclusion:** The most suitable image quality metric from CT data is noise, with no useful benefit obtained from consideration of tissue contrast. Weight and patient dimensions are equally satisfactory for predicting how noise varies with patient size, and are superior to the use of BMI.

SU-FF-I-09

Comparison of Radiation Dose Indexes For CT Scanners: Measured Verses Automated Scanner Calculations

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Purpose: Modern CT scanners provide radiation dose indexes such as CTDI and DLP for every patient based upon the selected scan parameters. Our goal is to study the potential sources of errors for these automated calculations. **Method and Materials:** The measured and automated radiation dose indexes were compared on five different CT models from two manufacturers. Acrylic cylindrical phantoms with diameters ranging from 6 – 32 cm were utilized for the study. Measurements were made at all available kVp's and typical scan techniques in both axial and helical modes. The measured CTDI and DLP values were compared with the displayed automated values. **Results:** The automated displayed CTDI and DLP values are derived from system calibration using fixed size phantoms representing a typical adult head (16 cm) and adult body (32 cm). They vary with parameters such as kVp, mAs, pitch, x-ray beam collimation and selected protocols. For typical adult head, our measured CTDI and DLP values agreed with the automated values to an average of 7.8% discrepancy. Similarly, an average of 14% discrepancy was observed for typical adult body. However, the discrepancies widened significantly for those measured on other sizes. For pediatric body scans using a 16 cm diameter phantom on table top, the measured CTDI values are more than doubled compared to the displayed automated values. **Conclusion:** It is important to realize that the automated radiation dose indexes by CT scanners only represent estimates based upon standardized adult body and head sizes. No considerations are given to patient age, size, weight and tissue composition. Especially, the values for pediatric scans are not represented correctly by the automated CTDIs. Future calculated radiation dose assessments needs to be incorporated with more patient factors.

SU-FF-I-10

Evaluation of a Micro-CT Scanner Applied to the Characterization of Pulmonary Architecture in the Rat

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Purpose: With the rapid demographic shift towards urbanization worldwide, increasing numbers of children are exposed to ozone and particulate pollutants as a result of closer proximity to transportation corridors. To quantify the effect that ozone has on mammals, a rat-lung cast model was developed and micro-CT techniques were used to image the lung casts at high spatial resolution. **Method and Materials:** A normal rat lung was characterized. At sacrifice, the trachea was cannulated, and a RTV silicone compound was injected by syringe into the airways and allowed to harden. The rat tissues were decomposed using acid bath, so that a cast of the respiratory tree of each rat remained. A custom designed micro-CT scanner was used to evaluate the lung casts. The system used a 70 micrometer focal spot tungsten anode, a rotating stage, and a 2048 x 1024 CMOS based indirect (Gd_2O_2S) detector. **Results:** CT scans were acquired using the full resolution of the detector, and using between 300 and 1000 projection images. A cone beam reconstruction developed in house was used to generate high resolution volume data sets (eg. 1024 x 1024 x 512) of the lung casts. **Conclusion:** The micro-CT scanner was able to accurately characterize the pulmonary structure of the rat from the lungs casts, and this approach was necessary to characterize the complex three dimensional pulmonary structures. This application of small animal imaging technology has enabled computer modeling and quantitative analysis of the biological issues surrounding ozone exposure using the rat model.

SU-FF-I-11

Investigation of a Method to Adjust Non Medical Grade Monitors Without the Use of a Photometer

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Purpose: Computer monitors with luminance range less than the ACR recommended value of 220 cdm^{-2} for diagnostic monitors are increasingly being used for the viewing of clinical images. One of the reasons is the increased popularity of Web applications that make clinical images easily accessible from office and home computers. In this study we investigate a quick and easy method for radiologists/clinicians to set-up the brightness and contrast of such monitors without the use of a photometer. **Methods and Material:** 17 commonly used flat-panel desktop monitors were visually optimized for low contrast resolution using the TG18-BR pattern. Since the monitors' low contrast resolution performance was found to be affected significantly less by the brightness setting than by the contrast setting, we fixed the brightness setting at 75% of maximum brightness and changed the contrast setting to further optimize the low contrast resolution After optimization, the display function of each monitor was compared to the DICOM Gray Scale Display Function (GSDF). After forcing the minimum and the maximum luminance of the monitor to fall on the GSDF we calculated the RMS error between the monitor display function and the GSDF for the 20%, 50% and 90% gray-scale values of the SMPTE pattern. **Results:** The mean value of the optimum contrast settings was 39.6% of maximum contrast with standard deviation of 21.8%, and a range of 0% to 63%. The RMS error ranged from 1.9 to 39 with an average of 17. The RMS error was poorly correlated with the contrast setting (r=0.21), 100% luminance (r=0.27) and 0% luminance (r=0.12). **Conclusion:** Further ROC studies are needed to determine what RMS errors relative to the GSDF are acceptable for viewing images of different types (e.g. CT or chest) on these monitors and whether window and level adjustments can compensate for larger RMS errors.

SU-FF-I-12

Boundary Based Vs. Region-Based Segmentation Techniques for Breast Lesion Phantoms Produced by Fischer's Full Field Digital Mammography Ultrasound System (FFDMUS): A Novel Tool for Performance Evaluation of LCD's and CRT's

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Purpose: This paper presents a performance evaluation strategy for LCD and CRT display characterization using ultrasound data acquired from Fischer's full field digital mammography and ultrasound system (FFDMUS) prototype. **Method and Materials:** Lesion segmentation of these ultrasound images acquired through the FFDMUS was performed using two approaches: (a) Gradient Vector Flow (GVF) and (b) Signal-to-Noise (SNR). The protocol consisted of FFDMUS ultrasound data acquisition with known X-ray and ultrasound parameters. The ultrasound ROI images were displayed on LCD and CRT displays, memory grabbed and then segmented using GVF and SNR tools. Note that during the memory grabbing process from the displays, the spatial properties of the displays were ignored. This output was then optimized for partial volume correction, given the ideal boundary. The performance of the segmentation algorithms was evaluated by quantifying the mean error between the ideal boundary and the computer-estimated boundary. Polyline distance metric (PDM) was used as a ruler. We used the segmentation and error quantification system on LCD and CRT displays. **Results:** we optimized our segmentation algorithm over 22 ultrasound FFDMUS images. The mean and standard deviation using GVF on LCD/CRT were 0.870 & 0.207/0.900 & 0.244. Correspondingly, the mean and standard deviation using SNR on LCD/CRT were 1.129 & 0.321/1.105 & 0.315. **Conclusion:** It was observed that both the segmentation strategies are comparable on both LCD's and CRT's for this data set used. Also the GVF performed better than SNR, as it was an interactive methodology.

SU-FF-I-13

Accurate Measurement of Lead Shielding In-Situ

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Purpose: To design a protocol for measuring or verifying the amount of lead in a wall of unknown thickness for purposes of radiation shielding in a diagnostic x-ray room. The aim is to develop a method of accurate measure for thicknesses up to 1/8 inch of lead that can be used with a simple scintillation counter attached to a standard survey meter. **Method and Materials:** We employed a simple scintillation detector connected to a digital rate/meter scaler combination and a scintillation detector attached to a multi-channel analyzer (MCA). Measurements were made for a Tc-99m source in a vial placed in a lead cylinder in alignment with a 1 inch by 1 inch scintillation detector. Lead sheets (2' x 2') were placed half-way between the source and detector. The energy spectra were obtained as well

as integrated counts with the survey meter. Background was determined and subtracted from the measurements. Different regions of the spectrum were investigated by integrating over varying energy ranges (variable low energy to 195 keV). A plot of the counts as a function of lead thickness were obtained and compared to the expected attenuation curve for a good geometry. In addition we have investigated the effect of collimation and source geometry. **Results:** As expected the results for a window about only the photopeak produced the expected logarithmic variation as a function of thickness given sufficient count statistics. At lower energy thresholds, the scatter caused significant deviation from the expected behavior beyond 1/16 inch. An effective half-value layer was derived as a function of lower energy threshold and thickness. **Conclusion:** We have developed a method to determine with reasonable accuracy the value of an unknown thickness of lead in the wall of an x-ray room using a scintillation detector with a digital survey meter.

SU-FF-I-14

New Approaches to Practical CT Dosimetry

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Purpose: To outline the basics of conventional CT radiation dosimetry, to discuss difficulties that new cone-beam and wide-area detector geometries present to this conventional dosimetry approach, and to illustrate the practical application of recently proposed dosimetry techniques to both multirow and cone-beam CT configurations. **Method and Materials:** Traditional CT radiation dosimetry is reviewed and its limitations in cases in which the radiation field is extended in the axial direction are discussed. Comparison is made between this approach, which is based on the use of the standard 100 mm pencil-type ion chamber, and a recently proposed technique employing a small "point detector" ion chamber (e.g. an RMI type TDC-100A with 0.1 ml volume)(RL Dixon, A new look at CT dose measurements: beyond CTDI, Med. Phys. 30, 1272-1280 (2003)). The specific corrections for using the small chamber are demonstrated in the case of full cone-beam CT performed with rotational angiography equipment (Siemens ARTIS BA neuro-angiographic room). A complete methodology for performing CT dose measurements with small chambers is presented. **Results:** Good agreement between the point chamber and pencil chamber methods was demonstrated for conventional CT geometries. Direct measurement in cone-beam geometry is not possible with the pencil chamber, but can be performed with the point chamber. The estimated patient doses for conventional CTA were compared to those delivered by rotational angiographic equipment performing cone-beam acquisitions and found to be larger by a factor of between 8 and 25, depending on the specific protocol employed. **Conclusion:** Modern CT equipment employs geometries that make conventional CT dosimetry inapplicable. The clinical physicist should be aware of this and of the necessity for developing new methods to characterize the radiation dose delivered to the patient.

SU-FF-I-15

Computed Radiography Dose Data Mining and Surveillance as An Ongoing Quality Assurance Improvement Process

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Purpose: The purpose of this ongoing quality assurance (QA) project is to use our Picture Archiving and Computing System (PACS) as a data mining tool to surveil the computed radiography (CR) sensitivity number (S-number). The S-number provides a good approximation of the average absorbed dose to the imaging plate and can be used as a general indicator of proper CR exposure technique and radiation dose. **Method and Materials:** Multiple CR systems acquire radiographic exams which are stored on PACS. A data mining program extracts the S-number information of the CR exams on a monthly basis. The S-number is approximately defined as S = 200/exposure (mR). A log transform is applied to the S-number data to normalize the skewed distribution of the S-number histogram. Data falling outside two SD are discarded to exclude extreme outliers. This data is compared with the previous month's data and initial baseline data to observe if trends are increasing or decreasing with respect to the departmental S-number goals (bone, spine and extremity exams=200, chest exams and general imaging including abdomen=300; all with ±15% range). The results are presented at monthly QA meetings with radiologists, technologist supervisors, physicists and administrators in attendance. S-number trends are then used by the technologists to modify radiographic technique charts to reach the S-number target range. The entire cycle is repeated monthly as an ongoing QA improvement project. **Results:** The mean S-numbers for main, trauma and portable radiology exams have increased by 69%, 67% and 46% over the past year respectively, corresponding to an approximate reduction in dose of 32%-41%. As a result of this process, we have adjusted our phototiming systems to reflect the S-number goals for specific anatomy. **Conclusion:** This cyclical QA process demonstrates that PACS data can be mined usefully to reduce radiation dose and inter-exam dose variance.

SU-FF-I-16

Calibration of TLD Chips to Maximize Accuracy in Radiographic Phantom Dosimetry

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Purpose: To develop an efficient annealing/readout protocol for TLD dosimetry that will maximize the accuracy and precision in radiographic dosimetry measurements. **Method and Materials:** 500 TLD chips were grouped in batches of 100 and subjected to varying annealing protocols and then irradiated to varying exposure levels. Three different annealing/readout protocols were tested. In protocol #1, the chips were annealed at 400 C for 1 hour followed by 2 hours at 100 C. The chips were exposed, and then allowed to rest for 24 hours before reading. In protocol #2, the anneal cycle was 400 C for 1 hour followed with a 30 minute cool-down, followed by 20 hours at 80 C. Immediately after exposure, the TLD's were heated to 120 C for 10 minutes, then read. In protocol #3, the anneal cycle was 400 C for 1 hour followed by a 30 minute cool-down, then 100 C for 2 hours. After exposure, the TLDs were pre-heated and read as in protocol #2. **Results:** For protocol #1, the inter-exposure uncertainty in the response (nC/mR) was approximately 4.2%. Using protocol #2, the intra-batch uncertainty was reduced to 4.0%, and for protocol #3 the uncertainty was reduced to ~3.7%. By using individual chip calibrations, the intra-batch uncertainty for estimating consecutive exposures was reduced to 3.5%, 1.8%, and 1.7% for protocols #1, 2, and 3, respectively. By binning TLD signals over groups of 3 chips, the uncertainty in estimating exposures was reduced to ~1.1% for protocol #3.
Conclusion: With careful calibration and binning of results, an accuracy approaching 1% is readily obtained. The anneal/readout protocol that yielded the highest accuracy also required the least time for a complete cycle, with a batch of 100 chips being processed in <1 working day using a single furnace for annealing and a single-chip reader.

SU-FF-I-17

Study On MOSFET Sensitivity Characteristics as a Function of Frame Rate in Modern Interventional Digital Pulsed Angiography/Fluoroscopy

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Purpose: Application of MOSFET technology in modern interventional pulsed digital angiography/fluoroscopy presents a new opportunity to measure organ dose in real-time using anthropomorphic phantoms. The purpose of this paper was to study MOSFET response characteristics to a series of short pulses (10 msec pulse width) at various frame rates. To the best of our knowledge, no data have been published on the response characteristics of high sensitivity diagnostic MOSFET using modern interventional pulsed fluoroscopy system. **Method and Materials:** High sensitivity MOSFET detectors (model TN-1002RD, Thomson-Nielson, Ottawa, Canada) and an ion chamber (model 10x5-6 ion chamber and model 9015 monitor, Radcal, Monrovia, CA) were exposed to a series of pulsed x-ray beams (pulse width 10 msec) at different frame rates and MOSFET response characteristics were studied as a function of frame rate. To simulate patient, aluminum plate (total thickness 1.5") was placed between the patient table and a flat panel detector. Philips Integris Allura 3-D rotational angiography system was employed. The frame rate was varied as follows: 0.5/s, 1/s, 2/s, 3/s, 7.5/s, 15/s, and 30/s. These frame rates cover entire spectrum of clinical applications; from interventional radiological

procedures to cardiac catheterization applications. **Results:** Normalized MOSFET responses (mV/Roentgen) were plotted as a function of frame rate and MOSFET responses were constant as a function of the frame rate. **Conclusion:** Using state-of-the-art interventional radiology x-ray system, we observed that response characteristics of the MOSFET remained constant as a function of frame rate. This suggests that MOSFET technology may be used for interventional angiography and cardiac catheterization dosimetry.

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SU-FF-I-18

A Comparison of NCRP 147 CT Shielding Methods

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Purpose: The NCRP report 147 describes two methods to calculate the shielding, one using a scattered fraction of the CTDI, and another using the scatter plot supplied by the manufacturer. The two methods are used to calculate shielding for a model CT suite, and the results compared. The calculation complexity and gantry attenuation are major differences. **Method and Materials:** The scatter fraction method only requires the CTDI, which is supplied by the manufacturer or available at IMPACTscan. The scatter plot needs to be adjusted to the room scale and overlayed. **Results:** The scatter fraction was simple but no consideration for attenuation of the gantry is made. The scatter plot gives the best information for the radiation near the ganrty

SU-FF-I-19

Skin Entrance Radiation Dose in An Interventional Radiology Procedure

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Purpose: Monitoring of skin entrance radiation exposure in lengthy interventional procedures with X-ray is recommended because of the potential for skin injury. X-ray on-time and dose-area product (DAP) are readily available real-time measurements. It would be of interest to study the correlation of these parameters and skin entrance radiation. **Method and Materials:** Twenty interventional procedures performed through the aortic arch to one or more of its three associated major blood vessels were monitored. Two pieces of GafChromic XR Type R film were placed between the patient and the examination table. An observer recorded the X-ray on-time and DAP for each phase of the procedure. Each film was scanned post-procedure in RBG mode, and then the red component of the image was analyzed for peak skin entrance radiation dose (in air kerma) after proper calibration. All DAP values were corrected according to a calibration with an ion chamber. With the corrected DAP values for the respective phases of a procedure, and the Monte Carlo model used by the National Radiological Protection Board (United Kingdom), the effective dose in a standard man was calculated. **Results:** For these twenty cases, the mean and standard deviation of were 17.2 $\pm$ 6.4 minutes for X-ray on-time, 256 $\pm$ 65 Gy.cm^2 for DAP, 94 $\pm$ 34 cGy for peak skin entrance dose in air kerma, and 13.2 $\pm$ 3.1 mSv for effective dose. The peak skin entrance dose was correlated to X-ray on-time, DAP and effective dose with the coefficients of 0.69, 0.68, and 0.49 respectively. The corresponding r-values in linear regression analysis were 0.48, 0.46, and 0.24. **Conclusion:** The poor correlation with DAP and X-ray on-time suggests that skin dose should be measured independently. However, peak skin entrance dose would be a poor indicator for effective dose. Determination of the latter requires more detail information.

SU-FF-I-20

Improved Image Quality And Dose Efficiency with a Next-Generation Interventional Cardiac Digital Flat Panel (DFP) System

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Purpose: Cardiologists are treating smaller coronary vessels using stents with less metal content and smaller micro strut thicknesses designed to reduce in-stent restenosis rates[1, 2]. We present the image quality and dose measurements of a next-generation digital flat panel (DFP) cardiovascular angiography system optimized to meet the needs of these demanding interventional procedures. Specific improvements include a detector with higher DQE at fluoroscopic (73% at 1μR) and record (79%) doses, optimized xray exposure factors based on a neural-net patient thickness estimation, and an xray source with higher fluoro power and increased range of spectral filtration. Performance improvements are demonstrated in a controlled comparison with the most widely installed state-of-the art DFP system. **Method and Materials:** Measurements of image quality and dose were made using the standard cardiovascular benchmarking SCAI-NEMA phantom on a state-of-the-art Innova®2000 and the new DFP system. Low contrast iodine visibility and phantom entrance dose were measured for simulated medium and large patient sizes using 20 and 30 cm thicknesses of polymethlymethacrylate (PMMA), respectively. Other measurements included limiting resolution, dynamic range and moving guide wire visibility, using the standard 20 cm phantom configuration. Measurements were obtained using normal mode, 30 frames per second (fps) fluoroscopy over all fields of view. **Results:** The new DFP system demonstrated significant improvement ($p<=0.05$) in low contrast iodine detectability, at equal or lower doses, and in moving wire visibility. Working thickness (dynamic range) was improved. Spatial resolution limits were comparable. **Conclusions:** The SCAI-NEMA measurements strongly suggest that, compared to the current state-of-the-art DFP system, the new interventional cardiovascular DFP system will provide better dose efficiency with a significant improvement in device and vessel visibility in a cardiac environment marked by anatomical motion. Images and data demonstrating stent visualization improvements will also be presented. **Conflict of Interest:** Authors are employees of a medical imaging equipment manufacturer.

SU-FF-I-21

Can Prostate CT Contouring Be Improved?

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Purpose: Contouring the prostate on a CT dataset remains a challenge, especially post implant. The prostate apex is not clearly defined on CT. It is difficult to distinguish the bladder neck from the base of the prostate. This study reports the variability in contouring the prostate on CT between individuals and the potential to reach a consensus with training**. Method and Materials:** Five post permanent prostate implant CT studies scanned using a Picker scanner, 2 mm slice thickness, were open for contouring to participants at an international meeting. Thirty-nine participants who routinely contoured the prostate contoured all 5 studies using the Variseed software. The volume of the prostate contoured with reference to the standard MR prostate volume is reported.
The same five studies were also contoured by 6 experienced radiation oncologist. The participants first received a tutorial on CT contouring techniques. They were provided with 3 test cases to practice and then asked to contour the five studies. **Results:** The average ratio of the CT to MR prostate volume for 39 participants without the tutorial was 1.09 $\pm$ 0.50, 1.68 $\pm$ 1.00, 0.92 $\pm$ 0.46, 1.12 $\pm$ 0.55, and 0.99 $\pm$ 0.56, respectively for the five cases. The same average ratio for 6 experienced radiation oncologists with training was 1.02 $\pm$ 0.09, 1.52 $\pm$ 0.35, 0.85 $\pm$ 0.19, 1.16 $\pm$ 0.17, and 0.94 $\pm$ 0.13, respectively. **Conclusion:** The average ratio of CT to MR prostate in both studies were comparable. However, the standard deviations for the study with training are small indicating that it is possible to reduce the variability in prostate contouring between individuals. **Conflict of Interest:** This work was supported by Oncura and Varian Medical Systems, Inc.

SU-FF-I-22

An Inward Mammilla Detection Algorithm for Analysis of Skin-Line Retraction

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Purpose: A specific algorithm is designed for the detection of the mammilla to locate the inward mammilla position along the breast skin-line in mammograms. The position of the inward mammilla can assist in the analysis of focal retraction near the nipple. **Method and Materials:** Between the breast skin-line and the fibro-glandular tissue is a zone of fatty peripheral tissue, which appears with low gray-levels on mammograms. Due to the mammary glands connecting to the mammilla, the gray-level in

the fatty zone near the mammilla will be higher. We define a fatty peripheral zone (Z_f) of 40 pixels width (8mm) parallel to the skin-line on mammograms. A disk mask of diameter 40 pixels, K_P, tangential to the skin-line boundary point P and rolling in the zone Z_f, is used to obtain a mammilla index value for P. A mammilla index (I_P) for P is defined as the average gray-level of the pixels in both Z_f and the current mask K_P. Then, three highest values, I_{t1} (highest), I_{t2} (second highest), and I_{t3} (third highest), corresponding to position indexes P_{t1}, P_{t2}, and P_{t3} on the skin-line, are found on the curve of I_P. If the differences between P_{t1} and P_{t2}, as well as between P_{t1} and P_{t3}, are larger than a threshold T_1, and the difference between P_{t2} and P_{t3} is less than another threshold T_2, the mammilla position is defined as the average of P_{t2} and P_{t3}; otherwise the mammilla position is defined as P_{t1}. Empirically, we selected T_1=90 and T_2=36. **Results:** We have tested our algorithm on 40 mammograms from the MiniMIAS database with inward nipples, and our method achieved accurate detection of the mammilla position on each image. **Conclusion:** The proposed algorithm for the detection of the inward mammilla position gave accurate results on the mammograms tested.

SU-FF-I-23

An Iterative Method for Flat-Field Correction of Digital Radiography with Arbitrary Detector Position

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Purpose: To investigated the effect of X-ray tube positions with respect to detector on the non-uniformity correction, and propose a method to reduce the effect using a new algorithm with computer simulation. **Method and Materials:** Gain images that represented the reference image used to execute the flat field correction were taken in two SIDs (Source to Image-receptor Distance). Pixel values at second SID was calculated using the pixel values at first SID, the assumed gain coefficient, and the formula based on the solid angle of each detector pixel facing to the x-ray source. Gain coefficient was adjusted using the difference between calculated and real pixel values at second SID. Calculation was repeated with new gain coefficient until the gain coefficient was converged into prescribed range. Flat field correction could be performed using acquired gain image. Non-uniformity of blank x-ray images taken with the detector tilted by 0 to 45 degrees was corrected and five ROIs across the image were defined and analyzed. **Results:** With a blank image obtained with the detector tilting angle of 45 degrees the lowest ROI mean value was 53% less than the highest ROI mean value when usual non-uniformity correction was performed. When the proposed was used for the flat field correction, however, the lowest ROI mean value was only 7% less than the highest ROI mean value, and standard deviations of pixel values in the ROIs were reduce to 10% of the cases of usual flat field correction. **Conclusion:** Because of the characteristic of usual flat field correction, non-uniformity in detector that was not aligned to the X-ray source considerably increased. We also calculated the gain coefficient and performed the flat field correction with the iterative method in the tilted or arbitrary detector position. The proposed algorithm gave a satisfactory uniformity.

SU-FF-I-24

Band-Pass Filtering Vs. Multiscale Dyadic Wavelet Transform for Contrast Enhancement of Digital Mammograms

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Purpose: This paper discusses two methods for contrast enhancement of digital mammograms. One method is based on the Gaussian band-pass filter and the other is based on the dyadic wavelet transform and multiscale non-linear enhancement. **Method and Materials:** Band-pass filter: A logarithmic tone mapping operator with adaptive base is applied to an image to elevate the lower intensities which lie mainly in the skin-line zone. The mammogram is then filtered using a Gaussian band-pass filter to enhance the structure of breast while suppressing noise and the slowly varying high density structure.

Dyadic wavelet enhancement: Dyadic wavelet transform is applied to an image to decompose the image into horizontal detail and vertical detail subband images at different scales. Then, a non-linear weighting function is used to modify the wavelet coefficients of each subband image followed by synthesis to yield the final enhanced image. The final enhanced image is obtained by synthesis of the modified subband images. **Results:** We compared the enhancement performance between these two approaches. Band-pass filter does a better job of elevating the skin-line zone to the intensity level of the interior of the breast and also enhancing the contrast. However, there are some ringing artifacts which lead to saturation in a few regions near the top and the bottom part of the image. The local contrast can be improved to emphasize both salient and subtle features of mammograms. However, the contrast of the skin-line zone can not be enhanced well by the dyadic wavelet enhancement. **Conclusion:** Band-pass filter is fast and can obtain a good result on skin-line zone except for some ringing artifacts. Dyadic wavelet transform can enhance the unseen and barely seen features but is weak on skin-line. We tested the above methods on MIAS and Fischer Imaging databases.

SU-FF-I-25

Target Flattener Combinations for Combined Therapy and High Contrast Megavoltage Imaging

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Purpose: To optimize target-flattener design in megavoltage (MV) x-ray beams for combined therapy and imaging purposes using Monte Carlo methods to quantify the effect of target-flattener material on treatment and imaging properties. **Method and Materials:** Carbon, aluminum, stainless steel and tungsten were used in various target-flattener combinations. The BEAM/EGSnrc Monte Carlo system was used to design flatteners to achieve beam flatness, by the AAPM definition, of under 5% over 20 cm and 40 cm diameter fields. Further simulations were used to determine contrast improvement. Results were compared to experiment for the cases of the conventional tungsten target with stainless steel flattener, a small-field aluminum flattener, and no flattener. Contrast, contrast-to-noise ratio and MTF were measured using a variety of phantoms (aluminum plates, CIRS CT, Pips-Pro QC-3). A preliminary experimental investigation of contrast improvement in MV CT was also done, imaging the CIRS and Pips-Pro phantoms, and the head of RANDO. **Results:** Measured treatment and imaging properties of the conventional flattener and small-field aluminum flattener validated the calculation approach. Calculated results demonstrate significant improvements in contrast using low-atomic-number targets or flatteners, using smaller flatteners that limit the field diameter to 20 cm, or removing the flattener altogether. The highest contrast is obtained with a carbon-carbon target-flattener combination. This combination results in a modest increase in the surface dose. The MV CT scans are visibly improved using the small-field aluminum flattener in place of the conventional flattener. **Conclusion:** The Monte Carlo results for low-Z target and flattener combinations show significant improvement in imaging properties with minimal degradation of treatment properties. Clinical implementation would lead to improved contrast in localization and verification imaging with megavoltage beams. With small-field flatteners, the dose gradient outside the flattened region could be compensated with IMRT. **Conflict of Interest:** This work is partially supported by Siemens Oncology Systems.

SU-FF-I-26

Performance Characterization of a New 41cm by 41cm A-Si Flat Panel X-Ray Detector

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Purpose: To quantify and report the performance of an a-Si flat panel X-ray detector with a new generation electronics design in terms of electronic noise, dynamic range and linearity, as well as to quantify the imaging performance such as MTF and DQE. **Method and Materials:** The new detector was designed to provide low noise, wide dynamic range and programmable gain for a wide signal range. The signal readout chip has 128 channels, and each consists of a charge integration amplifier, followed by a correlated double sampling stage and a 128:1 multiplexer. The output voltage from the multiplexer is digitized by a 16-bit analog-to-digital converter. The programmable gain can provide settings ranging from the most sensitive of ~250 electrons per counts (e-/c) to the least sensitive ~4,000 (e-/c). The detector uses a 41cm by 41cm a-Si flat panel with 200μm pixel pitch and was coated with CsI(Tl). The MTF and DQE

measurements were carried out in accordance with the IEC standard. **Results:** The total detector electronic noise is ~3200 electrons (500 e-/c), dynamic range was 78.3dB and the non-linearity is +/-1.5% over 10-90% of full signal scale range. The MTF and DQE were measured both with and without the protective front cover. **Conclusion:** The detector with the new readout electronics has met all the major design goals and has raised detector performance to a higher level.

SU-FF-I-27

The Effects of Fog On the Detectability of Radiographic Signals

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Purpose: To evaluate the effects of fog on the detectability of radiographic signals. **Method and Materials:** The effects of added fog on a general-purpose medical radiographic film were quantitatively evaluated in terms of threshold signal detectability using the CDRAD phantom under general radiographic conditions. Six observers evaluated threshold detectability within this phantom's uniformly exposed background at 36 combinations of x-ray exposure and added fog. Additionally, the visibility of faint radiographic signals was visually assessed by experienced observers for 20 different film brands, using an aluminum step wedge as a background for faint signals. These 20 films span a wide range of contrast and speed. **Results:** In all instances, adding background fog to radiographic film samples had minimal effect or improved the subjectively perceived and CDRAD phantom-assessed detectability of faint signals. **Conclusion:** The threshold detectability of radiographic films is not very sensitive to added fog level under the broad experimental conditions used. However, many current regulations and guidances prescribe very small tolerances within which fog should be maintained, sometimes as small as 0.03 in optical density. These data indicate that fog should be considered as a simple issue of meeting a radiologist's preference, and fog is not appropriate as a strictly proscribed performance specification. However, one may use short-term fog changes, assessed using a properly stored single box of film, as an indictor of potential film processing quality control problems. **Conflict of Interest:** The author is an employee of the Eastman Kodak Company

SU-FF-I-28

A Novel Simulated Method of Quantifying Susceptibilities in Objects: The First Step Toward Quantitative Diagnosis in MRI

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Quantifying tissue susceptibilities *in-vivo* is important because certain tissue susceptibilities may reflect health conditions of an individual. Many researchers have accurately measured susceptibilities of different materials using the least-square-fit method when the object sizes occupy at least 50 pixels on MRI. In this abstract we have developed a new approach to measure susceptibilities of small objects from MRI.

We first simulated a disk with a radius of 16 pixels on 4096×4096 magnitude and phase images. The disk was a cross section of an infinite tube, perpendicular to the main magnetic field in MRI. The magnitude inside the disk was zero but unity outside the disk. The echo time and the field strength were chosen as 5ms and 1.5T. The phase was then simulated according to the well-known physics laws in magnetostatics, with a -9ppm susceptibility difference inside and outside the tube. Through a low-pass k-space filter, the sizes of images were then converted to 256×256 such that the radius of the disk became roughly 1 pixel. The 256×256 magnitude and phase images would be almost identical to images acquired from a 1.5T MR system, with an air tube of radius 1mm perpendicular to the magnetic field and surrounded by water.

Our images were simulated with different tube radii as well as with and without Gaussian noises. Two circles around the disk were drawn on images. The centers of these two circles were coincided with the center of the disk. With each circle, the complex signal was summed. We were able to solve the susceptibility from an inverse approach, based on the known disk sizes, the comparisons of the obtained complex sums, and a theoretical model.

Without the presence of noise, the solved susceptibilities were within 1% accuracy compared to -9ppm. With the presence of noise, the results are more complicated.

SU-FF-I-29

Working Memory Deficits of Facial Images in Patients with Schizophrenia Using FMRI

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Objectives: Impaired processing of facial information is one of the broad ranges of cognitive deficits seen in patients with schizophrenia. We aimed to elucidate the differences in brain activities involved in the process of facial working memory between schizophrenic patients and healthy comparison subjects. **Method and Materials:** Twelve patients with schizophrenia were recruited along with twelve demographically matched healthy volunteers as a comparison group. Functional magnetic resonance imaging (fMRI) was used to assess cortical activities during the performance of a 1-back working memory paradigm using images of neutral faces as mnemonic content. **Results:** The patient group performed the tasks with reduced accuracy. Group analysis revealed that left fusiform gyrus, right superior frontal gyrus, bilateral middle frontal gyri/insula, left middle temporal gyrus, precuneus, quadrangular lobules and vermis of cerebellum and showed decreased cortical activities in the patient group. On the other hand, an increased level of activation in lateral prefrontal cortex and parietal lobule was observed from the patient group, all in the right hemisphere. **Conclusion:** A decreased level of activity in the left fusiform gyrus among the patient group implicates inefficient processing of facial information. An increased level of activation in prefrontal and parietal neural networks from the patient group confirms earlier findings on the impaired working memory of patients with schizophrenia.

SU-FF-I-30

Evaluation of Glass Capillary Material for Suitability of Use in a DTI Quality Assurance Phantom

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Purpose: To evaluate whether glass fiber capillaries, having inside diameters (~50 microns) somewhat similar to cellular dimensions, are a suitable candidate for use in a quality assurance (QA) phantom to characterize MR diffusion tensor imaging techniques. **Method and Materials:** Two phantoms containing glass capillary arrays were constructed. The first was designed to examine the success of injecting water into capillaries, and to show scanning characteristics in a high SNR/high-resolution scan series. This phantom was imaged in a 7T Bruker PharmaScan MRI scanner, and signal intensities in the capillary arrays were examined for uniformity of water injection. Diffusion anisotropy and eigenvectors were also calculated. The second phantom was designed to test the performance of capillary arrays in a clinical magnet, as per a QA phantom. Images from a 1.5T GE scanner were acquired, and processed to determine fractional anisotropy and principle diffusion eigenvectors. **Results:** Based on the methods above, water can be successfully injected into the capillaries based on the uniformity of signal after injection. Eigenvectors show diffusion primarily along the axis of the capillary array. Images from the clinical series also show diffusion along the axis of the array, even at the SNR and resolution typical of a clinical protocol. **Conclusion:** The work performed in this study suggests that glass capillary arrays could be used successfully in a QA phantom, in principle. Future investigations will determine the allowable range of capillary fiber inner- and outer-diameters, based on SNR constraints. Flexible arrays will also be investigated.

SU-FF-I-31

An Improved Method for Susceptibility Correction of MR Spectroscopic Images

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Purpose: Multivoxel spectroscopic imaging usually requires a correction for magnetic field differences between voxels. The correction enables a narrower frequency range for integration to produce the metabolic image, increasing the signal to noise ratio of the image. One method employs a single reference peak common to spectra in all voxels, such as n-acetylaspartate, NAA. This works well in all but tumor cases where NAA is not present. A manual search must be done to find and correct the spectra in those voxels by referring to the creatine or choline peaks. This is rather tedious so a method of using multiple reference peaks was developed. If the

pattern of the reference peaks is recognized, it can be used to correct for the magnetic field, automatically. **Method and Materials:** Data was acquired with the sequence from the NIH on 1.5T and 3T magnets from GE Healthcare. The sequence includes water saturation and outer volume suppression and allows for 4 slices to be acquired with a 32x32 matrix yielding a voxel size of 0.9 cc. The analysis was performed on Eigentool software with spectroscopy analysis code CSX. The reference peaks are defined by with a window and a maximum. The pattern of space between the reference peaks is compared to that of peaks larger than a second threshold. The pattern is allowed to shift up to one quarter of the span between the reference peaks. **Results:** The technique increases the speed of the analysis by decreasing the number of voxels that need to be checked manually from 100 or more to just the perimeter, perhaps 25, where the outer volume suppression may have missed some fat. **Conclusion:** Improving the analysis of MRSI can improve patient care by speeding up the time to report the results to the referring physician.

SU-FF-I-32

Detectability of Vasodilatation During Breath Holding by Dynamic CBV-Based MRI: Comparison with BOLD-Based MRI

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Purpose: To investigate the sensitivity of a CBV-based MR technique, vascular space occupancy (VASO) imaging, in the detection of vasodilatation during different durations of breath holding (BH) and its clinical feasibility as compared with BOLD MRI. **Method and Materials:** Experiments were performed on a 1.5T Siemens MRI scanner. For VASO, a non-slice-selective IR-GE-EPI was used with TR/TE/TI = 2000/9.3/665 ms, SW = 6 mm and in-plane resolution = 3 mm. For BOLD, a GE-EPI was used with TR/TE = 2000/ 60 ms. Two normal volunteers each performed 4 experimental runs, including two-cycle 30-s and 15-s BH each for BOLD and VASO. CNRs of were determined from ROIs drawn within the thalamus. A similar protocol was also carried out in a patient with right frontal anaplastic astrocytoma to review clinical feasibility. **Results:** Positive BOLD signal changes were noted during 30-s and 15-s BH (4.9 and 2.2 %), and the CNRs were 4.0 and 2.5. VASO method was able to detect CBV related negative signal changes (-3.1 and -1.8%, for 30-s and 15-s BH), and the CNRs were 2.3 and 1.8. Initial analysis of the patient data set revealed negative intra-tumoral BOLD signal changes. While the global pattern of the VASO map agreed well with BOLD, the extent of intra-tumoral changes was smaller. The BOLD map was then re-thresholded to a lower p-value which demonstrated intra-tumoral changes similar to those with VASO. **Conclusion:** CNRs of VASO were lower than those from BOLD. However, they were closer to BOLD (58 and 72% for 30-s and 15-s BH) than previously published results from visual stimulation (~ 30%). Discrepancies between two techniques in the clinical case were likely resulted from the differences in sensitivity. However, given that CBV-based signal change is more directly related with the vasomotor response, it could potentially be more clinically relevant.

SU-FF-I-33

T2-Weighted Prostate Imaging Using Echo-Planar Imaging at 3T

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Purpose: T2-weighting in fast spin echo (FSE) images is unavoidably affected by T1-mixing due to stimulated echoes. The purpose of this research is to evaluate the feasibility of using a multishot echo-planar (EPI) technique to image the prostate at 3 Tesla without an endorectal coil and to compare T2 quantification using EPI with that based off of FSE images. **Method and Materials:** All experiments were performed on a GE Signa 3 Tesla whole body scanner with an 8-channel torso phased-array coil. T2-weighted images were acquired of a healthy volunteer at echo times (TEs) of 40, 80 and 110 ms with a multishot spin-echo EPI. Other imaging parameters were: 32cm FOV, 16 shots, TR = 2000ms, acquisition matrix = 256x512, receiver bandwidth = ±250 kHz. FSE images were obtained of the same volunteer with TEs of 60, 120, and 180ms and these acquisition parameters: 16cm FOV, TR = 3900ms, acquisition matrix = 256x256, ETL = 16, bandwidth = ±32kHz. A total of eleven slices covering the entire prostate were collected using both techniques. **Results:** The EPI images showed few artifacts and were noted to provide better T2-contrast than the FSE images. For a region-of-interest in the peripheral zone of the prostate, T2 values derived from FSE images (134±15 ms) are substantially larger than those based on EPI images (76±1 ms). This observation is consistent with the apparent lengthening of T2 due to T1 mixing in FSE images. **Conclusion:** Using EPI with high receiver bandwidth, our results indicate that high quality T2-weighted images of the prostate can be obtained at 3T without an endorectal coil. T2-weighted images by EPI provide pure T2-contrast and possibly more accurate T2-determination than conventional FSE images.

SU-FF-I-34

PSF and S/P in Mammography: A Validation of Simulations Using the GEANT4 Code

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Purpose: To study GEANT4 predictions for low-energy (10-40 keV) photon transmission and scattering through tissue-like thick matter, specifically to compare the predicted scatter to primary ratio (S/P) and line and point spread functions (LSF and PSF) against published and new measurements. **Method and Materials:** Using the GEANT4 code we have performed Monte Carlo simulations of the 1978 Barnes and Brezovich beam stop measurements of S/P, and the 2000 Cooper et al. edge detection experiments to evaluate S/P and LSF. Also, we have measured the PSF with a tungsten 1 mm diameter collimator on 3 – 6 cm thick lucite phantoms, using a Senographe 2000D unit operated at 26-28 kVp. In the simulations we have reproduced the exact experimental geometrical conditions, as well as the rest of parameters, according to the information contained in the original reports. **Results:** The S/P simulation and data agree within 3-10% accuracy, depending on the data set. The largest difference is with respect to Cooper et al., probably partially related to an inaccurate simulation of the original experimental conditions. For the LSF, the agreement between simulation and data is better than 15%, and for our PSF, better than 12 % at distances smaller than 5 mm. This last value should be taken as an upper limit, because of the lack of complete information on the features of the clinical unit. **Conclusion:** The analysis of these comparisons confirms that the GEANT4 predictions for low energy photon scattering are described with an accuracy better than 12%, at least up to 8 cm tissue thickness.

SU-FF-I-35

Scatter Correction For Digital Tomosynthesis

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Purpose: To investigate post acquisition scatter correction for digital tomosynthesis breast imaging. **Method and Materials:** Images of a composite phantom that was fabricated for evaluating digital breast tomosynthesis and used in a previous contrast-detail (CD) study [Suryanarayanan et al., Acad Radiol 7: 1085-1097, 2000] were used to test the scatter correction method. These images were acquired using a prototype full-field digital mammography (FFDM) system (GE Medical Systems, Milwaukee, WI) without an anti-scatter grid. The phantom comprised of a centrally placed CD insert (MedOptics, Tucson, AZ), blocks of cluttered paraffin and polymethyl methacrylate (PMMA), and beeswax surrounding it to provide a total phantom thickness of 54 mm. A set of 7 projection images of the phantom were acquired over an angular range of $\pm 18^{o}$ at 6^{0} intervals at 26 kVp, MoMo, and 32 mAs/view. The projection data sets were corrected for scatter using the scatter correction technique described by Trotter et al. [Proc. SPIE, vol. 4682: 469-478, 2002] and processed with an adaptive noise filter. The projection images were then reconstructed using back-projection and iterative restoration methods using Tuned Aperture Computed Tomography (TACT) [Webber et al., J. Digit. Imaging, 13: 90-97, 2000] software (developed by R.L. Webber, Wake Forest University, NC). The contrast-to-noise (CNR) ratio, signal-to-noise ratio (SNR), and % contrast were computed for one of the targets (2.32 mm diameter and 0.24 mm depth). **Results:** The uncorrected projection data set reconstructed with back-projection resulted in CNR = 3.0, SNR = 30.4, and % contrast = 11.1, while the scatter corrected and processed projection images yielded CNR = 10.2, SNR =60.7, and %contrast = 20.2. **Conclusion:** The results of this study indicate improved SNR, CNR, and %

contrast after scatter correction in tomosynthesis. We are currently implementing and evaluating other scatter correction and reconstruction methods for digital tomosynthesis.

SU-FF-I-36

Average Glandular Dose with Sectra MDM in Routine Mammography Screening

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Purpose: The aim of this work was to implement different International protocols to estimate average glandular dose levels for the first Sectra MicroDose Mammography (MDM) unit used in routine mammography screening (Helsingborg, Sweden). **Method and Materials:** The Sectra MDM is a scanning multislit digital mammography system which uses a direct photon counting technique with a solid-state detector, Si(B). A substantial dose reduction can be expected due to high photon absorption in the detector (90%) and scatter rejection (97%) as well as improved energy weighting compared to other mammography systems on the market. The multislit pre-collimator scans with a distance of only 115 mm above the breast support making it impossible to follow the usual procedure for half value layer (HVL) measurement. Instead, a sensitive and well-collimated solid state detector with simultaneous correction for the energy dependence (Barracuda X-ray multimeter, RTI Electronics AB, Sweden) is used for non-invasive measurements of the HVL. **Results:** The average glandular dose was found to be e.g. 0.28 mGy for a 50 mm standard breast with 50 % glandularity simulated with 45 mm PMMA according to the so-called European protocol from 1996. **Conclusion:** Methods of how to perform absorbed dose measurements according to European and American protocols on the Sectra MDM have been developed. The average glandular dose is much lower than for any other mammography unit on the market today. However, for increased accuracy, the dose protocols should be revised to account for the anode/filter combination used with the Sectra unit (W/Al), the scattered radiation from the multislit pre-collimator device and the occurrence of a dose profile in the scanning direction.

SU-FF-I-37

Heel-Effect in Screen-Film Mammography Artifact Analysis

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Purpose: To quantify the effect of mammographic x-ray field inhomogeneity due to the "heel effect," which is routinely observed during the medical physicist's artifact analysis of screen-film mammography (SFM) systems, and to assist the medical physicist when evaluating artifact analysis test films. **Method and Materials:** Artifact tests were performed on a variety of common SFM systems using typical screen-film combinations following the method of the 1999 ACR Mammography QC manual, which is consistent with MQSA requirements for medical physics surveys and equipment evaluations. Measurements of the optical density of 24 x 30 cm test films provided a measure of the density profile along a line parallel to the anode-cathode axis. To measure the x-ray field intensity profile independent of screen-film characteristics, a narrow strip of optically stimulated luminescence (OSL) material was placed on top of the uniform acrylic slabs. **Results:** Test films demonstrated reduction of optical density with distance from the chest wall for all x-ray machines tested and all screen-film combinations tested. Variation in the degree of density reduction was observed among individual x-ray machine models and for different screen-film combinations. The OSL data correlated the trends in x-ray exposure with those in optical density observed on test films. **Conclusion:** The "heel-effect" is a well-known source of field inhomogeneity which can be amplified by the contrast of the screen-film combination. This industry-wide sampling illustrates the range of variation to be expected both in terms of x-ray exposure and film optical density and provides a guide to the medical physicist who must evaluate whether or not an individual artifact analysis test result is "Acceptable". **Conflict of Interest:** J.S. is employed by a manufacturer of mammographic x-ray systems. J.G. is employed by a manufacturer of OSL media.

SU-FF-I-38

Mask-Based Vs. Reverse Engineering-Based Strategies for Skin-Line Enhancement in Low Contrast Projection Mammograms

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Purpose: This paper presents two new strategies for skin-line enhancement in mammograms based on brightness preserving bi-histogram equalization (BBHE) [1] framework during window and level process. **Method and Materials:** Image enhancement is performed using two different strategies based on BBHE framework: (A) masked-based strategy, and (B) reverse engineering approach. In the first approach, the image is divided into two regions: skin-line zone mask and the rest of the breast region. The skin-line zone mask is computed by subtracting the binary images obtained using two different threshold techniques: whole breast region threshold using Ojala's method [2] and stroma breast region threshold using Otsu's method [3]. The BBHE is then applied in this masked zone and the remaining breast region, thereby boosting the skin-line zone of the mammograms.
The second approach uses the reverse engineering technique where the enhancement is started in the reverse direction from skin-line towards the parenchyma. The bands are taken from the outer region of the breast moving inward. This method is implemented by performing BBHE on a significant band (say 50 pixels wide) on the image and replacing only a small band (say 10 pixels wide) by the enhanced BBHE band. This is repeated until the whole image was enhanced. This method performs very well on mammograms with very low contrast in the skin-line zone. **Results:** Both techniques demonstrated a considerable boosting in the skin-line zone, which was the goal of the enhancement process. The lesion conspicuity is improved and skin-line edges are well seen during window level. The algorithm has been tested on 15 MIAS mammograms. **Conclusion:** Both implemented methods show enhancement in the skin-line region. We are currently testing its robustness on other mammogram databases.

SU-FF-I-39

A Computer Simulation Platform for the Optimization of Breast Tomosynthesis System

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Purpose: In breast tomosynthesis there are tradeoffs between optimization of resolution, noise and acquisition speed with a given glandular dose. Our purpose is to provide a simulation platform to investigate any plausible configuration for a tomosynthesis system, and find an optimal combination of these parameters. **Method and Materials:** Simulated projections of a slanted thin tungsten wire placed in different object planes are modified according to a detector's MTF (binned or not binned). In addition, the focal spot blur (FSB), which depends on the location of the wire, the system geometry, the source-detector movement speed and exposure time, is also incorporated into the projections. Then a maximum likelihood (ML) algorithm is used for 3D reconstruction. The in-plane and in-depth MTF were determined. To evaluate the noise performance, simulated noiseless projections of calcification and tumor in uniform breast tissue were modified with real detector's NPS and for a given detector noise and dose. The signal to noise ratio (SNR) of the reconstructed images is calculated with different configurations, e.g. view number and angle, pixel binning and FSB. **Results:** The FSB is determined by the exposure time of each view at a fixed gantry travel speed. For SID = 65cm and exposure time $\leq$ 80ms per view, the 2x2 binning causes more degradation for the in-plane resolution than the FSB and reconstruction blur. The in-depth resolution can be improved by increasing the number of views and the span of view angle. However the SNR will be degraded because with the lower exposure per view (total dose constant), the detector performance is degraded by electronic noise. **Conclusion:** Many design parameters need to be considered for optimizing a tomosynthesis system. We provide a simulation platform to predict system performance with different configurations in advance. It will be helpful for practical implementation of breast tomosynthesis.

SU-FF-I-40

Image Registration and Voxel Based Analysis for the Differential Diagnosis of Corticobasal Degeneration and Progressive Supranuclear Palsy

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Purpose: This study measured the cerebral glucose metabolism in patients suffering from corticobasal degeneration (CBD) and progressive supranuclear palsy (PSP). PSP and CBD are neurodegenerative disorders that may be accompanied by dementia and parkinsonism as clinical symptoms. The aim was to determine if there was a different metabolic pattern using ^{18}F-labeled 2-deoxyglucose (^{18}F-FDG) positron emission tomography (PET). **Method and Materials:** The regional cerebral glucose metabolism was examined in 8 patients with a clinical diagnosis of CBD (mean age 69.6 ± 7.8 y; male/female: 5/3), 8 patients with probable PSP (mean age 67.8 ± 4.5 y; male/female: 4/4) and 22 healthy controls. Statistical parametric mapping (SPM) using a voxel by voxel approach ($p<0.001$, 200 voxel-level) was used to compare the regional cerebral glucose metabolism between the 3 groups. **Results:** Compared with the normal controls, asymmetry in the regional glucose metabolism was observed in the parietal, frontal and cingulate in CBD patients. In the PSP patients, the glucose metabolism was lower in the orbitofrontal, middle frontal, cingulated, thalamus and mid brain than their age matched normal controls. A comparison of the two patient groups demonstrated relative hypometabolism in the thalamus, the mid brain in PSP and the parietal lobe in CBD patients. **Conclusion:** These results suggest that when making a differential diagnosis of CBD and PSP, voxel based analysis of the ^{18}F-FDG PET images using SPM might be a useful adjunct tool in clinical examinations.

SU-FF-I-41

Phased Attenuation Correction in Respiration Correlated PET/CT

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Purpose: Evaluate the potential of phased attenuation correction in respiration correlated PET/CT. **Method and Materials:** Respiration correlated scans were made on a Siemens Biograph PET/CT scanner which was modified to make an extremely low pitch CT scan and list mode PET scan possible. After collection of the raw CT, list mode PET data, and the respiration signal via a pressure load cell, PET/CT images were binned into ten phases of the respiration with help of in-house built software. Attenuation correction was next performed for each phase.

Experiments were performed with a lollypop phantom. The sphere at the end of the rod was filled with approximately 20MBq FDG. For the first experiment a sphere with a diameter of 3.3cm was used. The second experiment was performed with a large sphere with a diameter of 3.7cm in which a second smaller sphere of 2.2cm was situated. The inner sphere was filled with water or air in order to simulate a tumor with a necrotic core. The sphere movement had an amplitude of 5.0cm, and a frequency of 0.3Hz. **Results:** Both CT and PET images of the ten phases in the first experiment show well-defined spheres in all orthogonal directions. In phased PET images corrected with the phased CT data, the sphere has a clearer outline as compared to images that were corrected with uncorrelated CT data.

The images of the second experiment indicate that phased attenuation correction also results in a better detection of inhomogeneous structures. **Conclusion:** In this phantom study we have shown that phased attenuation correction after respiration correlation of CT and PET is feasible. Application of phased attenuation correction reduces motion artifacts and improves image quality. In future research the feasibility of phased attenuation correction in PET/CT for lung cancer patients will be examined.

SU-FF-I-42

Imaging Technique in Estimating Lung Shunting of Yttrium-90 Microspheres

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Purpose: This study was to evaluate lung shunting from Tc^{99m} MAA and Y^{90} imaging, and its effect on treatment planning. Y^{90} Microspheres (Therasphere, MDS Nordion) have been used for the treatment of unresectable hepatocellular carcinoma (HCC). Tc^{99m} MAA imaging is utilized to assess pulmonary shunting which will affect treatment dose. Standard shunting compares the ratios of activity in the liver and lungs. **Method and Materials:** Twenty five patients were randomly selected to examine shunting ratios. Eight studies required the redrawing of RoIs to correct the variance in geometric mean. Actual activity was determined following treatment planning guidelines based on standard and measured shunting. Y-90 imaging of patients was also investigated for radionuclide distribution. **Results:** Inadequate RoIs were identified in 8 patients, which yielded up to 5% (mean 0.79%, STD 1.76%) difference ($p=0.90$) in lung shunting. The treatment dose showed 5.29% (mean 0.74%, STD 2.21%) deviation ($p=0.91$) caused by the ratios. It was further compared with standard ratios of 4% for none-HCC and 7% for HCC. Difference in the treatment doses from corrected ratios and the standard was: mean 9.01%, STD 19.7%, $p=0.19$ for the 4% and mean 5.18%, STD 19.0%, $p=0.55$ for the 7%. Y-90 patients images did not provide activity distribution in lungs when there was high shunting based on Tc^{99m} MAA imaging, but demonstrated Y-90 activity in liver. **Conclusion:** Tc^{99m} MAA imaging is important in treatment planning to avoid error from lung shunting. RoIs should be accurate and consistent to reduce error in treatment dose. Y-90 imaging depends on scatter characteristic of tissue and does not yield appropriate shunting images with Yttrium-90.

SU-FF-I-43

Problems and Techniques in Gamma Camera Imaging of Yttrium-90 Labeled Radiopharmaceuticals

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Purpose: This study was to identify problems and investigate camera parameters that would create effective biodistribution images for treatment planning and dosimetry in patients receiving Y-90 radionuclide therapy. **Method and Materials:** Y-90 **e**nergy spectra under different interacting conditions were recorded from MCA, uptake probe and gamma camera. Y-90 (17.6 MBq) was added to an Anthropomorphic Torso Phantom, with or without water in its tank, with following distribution: liver, 70% with water; right lung, 15% with water; left lung, 15% without water. Imaging was performed on a Siemens eCam, dual head camera with HEGP/MEGP collimators at various energy settings. Y-90 patient imaging was performed with retained activities of 1.52 GBq and 6.7 kBq Y-90 labeled microspheres and with 3.7 GBq Y-90 labeled Zevalin. At 30 minutes post Zevalin injection, a whole body scan was performed using a 194 cm bed length (5 cm/min, total 48 min), 256 x 1024 x 16 matrix without zooming. **Results:** Y-90 spectra indicated a characteristic X-ray peak (Pb. K-alpha) at 75 keV along with characteristic Bremsstrahlung distribution. Phantom tests found an energy window of 75 keV/50% to produce practical images. Significant uptake in the right lung of the phantom versus other structures was identified. Patient's lungs could not be easily visualized. **Conclusion:** An energy window (75keV/50%) is adequate for characteristic X-ray and Bremsstrahlung imaging. Y-90 imaging depends on scatter characteristic of tissue and does not provide direct biodistribution of Yttrium-90. Further investigations of imaging technique are needed to assess effective Y-90 patient imaging.

SU-FF-I-44

Air Bubble-Free Motorized PET-CT QA Phantom with Shielding Well

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Purpose: Performance phantom for PET-CT scanner (Philips Gemini scanner, UK) with special features such as air bubble-free, motorized shaking mechanism, and >95% shielding well is designed to evaluate imaging performance of the scanner. **Method and Materials:** The phantom consists of three parts: (1) a phantom, (2) a motor, (3) a carrier device with 4cm thick Lipowitz shielding well. The phantom is implemented in a 16cm-diameter * 25cm-length water phantom with acrylic housing. Various internal structures include (a) many discs for linearity, resolution, (b) cones for axial coordinates, and (c) a long disc holder for fixing each disc and for shaking. Each disk has two small wings in the disc edges, thus effectively perturbing water while it is rotating. Proper discs can be chosen and inserted in the disc holder. The holder is inserted onto the housing and extended out of the phantom, and connected

to a motor via a plastic belt, thus making possible rotating the internal structures. Also, the phantom has a conical top in the internal cylinder housing, so air bubbles produced during rotation are pushed toward an air pocket and trapped there. The radioactive material is injected through the air pocket, and plugged. The phantom is placed in the radiation shielding well while it is prepared. **Results:** The shaking mechanism of the PET-CT scanner is evaluated with different shaking speeds and different amounts of radioisotopes (0.1 to 10mCi 18FDG). The air bubbles are eliminated 100% during shaking mechanism, and does not introduce any artifacts in even CT images. Total preparation time with this phantom is about 10 minute. The shielding well attenuates radiation exposure by 95%. Detailed measured data will be presented. **Conclusion:** The phantom was very handy and effective to measure simple imaging QA in 10 minute preparation time with minimum radiation exposure.

SU-FF-I-45

Effects of Patient Positions On PET Tumor Volume Assessment in Lung Cancer

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Purpose: The purpose of this study is to investigate the effects of different patient positions on the PET and CT image registration, and to delineate more accurate PET metabolic tumor volumes (MTVs) using a deformable image registration in lung cancer. When PET and CT systems are used as stand alone modalities, the patient arm positions are usually different. We used a deformable image registration method to fuse PET and CT images with different patient positions. **Method and Materials:** PET and CT images were acquired for 10 lung cancer patients. Both arms were placed at sides for PET imaging, but arms were up for CT imaging. The images were registered using an iterative non-rigid algorithm (REVEAL-MVS) based on voxel intensities. The displacements after the image registration were measured in the lung boundaries with axial and coronal images. The MTV and its mean standardized uptake value (SUV) in the PET images were measured before and after the non-rigid image registration. **Results:** The displacements in the lung boundaries and diaphragm ranged from 1.85 to 3.89 cm for coronal images and from 1.57 to 2.42 cm for axial images. In 5 out of 10 cases the PET-MTV became greater and the mean SUV became smaller after the non-rigid image registration. The PET MTVs before and after the deformable image registration resulted in the volume differences of -1.8 cm^3 to +29.3 cm^3 and in the percent difference of –25% to +41%. **Conclusion:** The different patient positions (arms-down for PET; arms-up for CT) in stand alone PET and CT systems yielded different PET tumor volume, extent and location. The non-rigid image registration should be used to obtain more accurate PET MTV and its location. The PET MTV using a deformable registration method may be utilized for CT-based radiation treatment planning in lung cancer.

SU-FF-I-46

Performance Evaluation and Comparison of Two Cadmium Zinc Telluride Gamma Cameras

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Purpose: We evaluate and compare the imaging performance of two prototype Cadmium Zinc Telluride (CZT) gamma cameras. The long-term use of these systems is gamma-ray imaging of small animals and laboratory research. **Method and Materials:** The two systems, made by Mosaic Imaging Technology, Inc., using CZT modules and components from IMARAD, Ltd., consist of a 25-module carrier board, power supplies, and pulse processing and data acquisition boards. In testing we used 2 modules in the original prototype and 3 modules in the newer system. Each CZT module is a 38x38x5 mm monolithic crystal divided into 16x16 pixels, with two logic/pulse-shaping ASICs. The original prototype uses older ASIC designs. We developed detector initialization and control software in LabVIEW 7.0. In operation, the detector processes each gamma ray interaction to produce energy and pixel information, which the LabVIEW program converts into energy spectra and images. The imaging performance of the two systems is evaluated using the NEMA NU 1 (2001) guidelines. Performance tests include energy resolution, spatial resolution, flood field uniformity, linearity and count rate performance. **Results:** In operation, the original prototype's modules generally show better performance than the newer modules, which require more tuning to achieve satisfactory imaging performance. Intrinsic spatial resolution is limited by the 2.4-mm pixel pitch of the CZT modules. The original prototype's overall energy resolution is 7.2% FWHM for Tc-99m and somewhat worse for the new system. Energy resolution for individual pixels is even better, but photopeak locations vary. Linearity, uniformity and count-rate performance are comparable for the two systems, but the new modules generally have more dead pixels than the older modules. **Conclusion:** Individual CZT pixels have superior energy resolution compared to NaI(Tl), but intrinsic spatial resolution is slightly worse. The large pixel size impacts the utility of CZT gamma cameras for high-resolution applications.

SU-FF-I-47

Air Bubble- Free Motorized Flood Phantom

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Purpose: An air bubble-free flood phantom with grid patterns is fabricated to measure extrinsic resolution and linearity of PET scanner. It is designed to implement a 99m-Tc flood phantom with motorized water pump to reduce the shaking procedure as well as reduce radiation exposure to workers. **Method and Materials:** The flood phantom is fabricated with circular (50cm diameter) and rectangular shapes (60cm*40cm) to measure the extrinsic resolution of conventional gamma camera. It has a handle in which an air pocket and water pump are placed. The air pocket is made of two chambers with conical valve between them. During the shaking procedure, the air bubbles are sucked into to the air pocket due to gravity effect and water perturbation. Once the air bubbles are trapped in the air pocket. They could not escape from it. After the radioisotopes are injected through a pin hole in the air pocket, water pump is turned on. The shaking procedure starts. In order to estimate the effectiveness of the shaking mechanism, the survey meter with well-guided collimator is manually rotated on the flood phantom until uniformity of 3% is reached. It take approximately 5 minutes to mix the water with radioisotopes thoroughly. **Results:** The phantom is used to evaluate the extrinsic resolution and to estimate the uniformity/linearity of gamma camera or SPECT camera.. The images are analyzed to quantitatively measure the integral and differential uniformity and the non-linearity of the imaging system. The detailed data will be presented in the meeting. **Conclusion:** The phantom was very handy and effective to minimize radiation exposure to an operator. The multi-channel ionization chamber will be replaced manual rotation procedure to design fully automatic monitoring system.

SU-FF-I-48

A Comparative PET Study of Regional Cerebral Metabolism with Multiple System Atrophy

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Purpose: The ^{18}F-FDG PET images of the Multiple System Atrophy (MSA) and Idiopathic Parkinsonian Disease (IPD) patients were assessed by statistical parametric mapping (SPM) and image registration in order to determine the useful metabolic patterns between the two groups. A differential diagnosis of IPD and MSA is difficult due to the common of signs and symptoms. The aim of this study was to compare the regional cerebral glucose metabolism of MSA from IPD. **Method and Materials:** Eight clinically probable, IPD patients (3/5:M/F; age, 67.9 ± 10.7 y) and 11 probable MSA patients (4/7:M/F; age, 58.5 ± 8.4 y) were included in the study. Twenty-two ages matched healthy controls (9/13:M/F, age, 67.8 ± 14.4 y) were examined and were used as the controls for the comparison between the patients with Parkinsonism. All subjects underwent ^{18}F-FDG PET. **Results:** The IPD patients was found to have significantly low hypometabolism in comparison with the healthy controls on the prefrontal and lateral frontal cortex, the parietotemporal cortex, and the cingulated and caudate ($p \leq 0.01$, 100 voxel-level). As to patients with MSA, hypometabolism was observed in the putamen, pons and cerebellum in comparison with the healthy controls and IPD patients. Voxel-based analysis of ^{18}F-FDG PET showed detailed differences between IPD and MSA, which may be useful for differentiating both disease entities, evidenced by the correlation of glucose metabolism with the disease severity and the dopamine agonist medication. **Conclusion:** Voxel-based

analysis of ^{18}F-FDG PET showed detailed differences between IPD and MSA, which may be useful for differentiating both disease entities, evidenced by the correlation of glucose metabolism with the disease severity and the dopamine agonist medication. The ^{18}F-FDG PET images using mapping analysis might be a useful adjunctive tool for a clinical examination when making a differential diagnosis of Parkinsonism.

SU-FF-I-49

The Effects of Magnetic Field On Energy Resolution and Linearity in SPECT System

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Purpose: Inside a Photomultiplier tube (PMT) electrons are accelerated. When directions of electron are perpendicular to earth magnetic field, Lorenz force could be equivalent to 10V cross voltage applied to PMT. Such force divers electrons and considerably change the electron multiplication, hence the gain of PMTs. In this study, we evaluated the effects of magnetic field in photo peak , energy resolution and line spread shifting in three SPECT systems when the heads rotate in different angles.. **Method and Materials:** Three SPECT system available in our department were examined. One Pointe source including 5 mCi of ^{99m}Tc were fixed on the face of collimators (LEHR). The peak and FWHM of energy spectrum were determined. Then two Line sources of 5 cm long including 150 μCi of ^{99m}Tc were fixed on the face of collimators (LEHR). The linearity were determined. The procedure was repeated while heads rotate in different angles. One air conditioner was placed at 3-meter distance from the camera gantries and the whole procedures were repeated . **Results:** In all three systems the maximum variations observed in energy photo peak ,peak of LSF and linearity are statistically significant ($p<0.01$) when the heads rotate in earth magnetic field. when the air conditioner was functioning, the height of energy spectrum peak was less than when the AC was off. In one of the system variation were much more prominent than the two other systems. This most probably was due to orientation of the system not to intrinsic construction. **Conclusion:** When the heads of SPECT systems rotate ,the magnetic field can vary energy resolution and linearity of systems. It is suggested that when SPECT systems are installing, the setting orientation be noted more accurately.

SU-FF-I-50

Detectability Study On OCT in the Presence of Speckle with Hotelling Observer

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Purpose: To study the detectability performance of an Optical Coherence Tomography imaging system in the presence of speckles within the framework of the Hotelling observer. **Method and Materials:** Optical Coherence Tomography (OCT) is a non-invasive imaging modality widely used in in-vivo study of tissues. Optical propagation in biological samples is dominated by scattering due to fluctuations in refractive index. This random fluctuation in the index makes it necessary to model the samples as random fields and statistical analysis the tool of choice. The Hotelling observer, a numerical observer that forms its test statistic based on the covariance of the input data, will be used in the classification task of distinguishing one class of sample from the other. The input of the Hotelling observer (i.e., the OCT signal) is considered to be generated by mixing the reference beam with the backscattering of the mean field in the sample. The scattering is handled by using the 1st Born approximation. Poissonian imaging noise will be considered. **Results:** An expression of the detectability index is derived for a classification task within the framework of the Hotelling observer. With this expression, we study how the sample properties and the layout of the optical system affect the performance of an OCT system. **Conclusion:** This work sets the foundation for the assessment of the OCT system and system optimization with respect to a classification task. The stochastic model used to describe the sample is more general in the sense that it goes beyond Gaussian statistic, and the functional form is easy to adjust to include different types of sample.

SU-FF-I-51

Interoperability Validation of DICOM Portable Data for Imaging in Nuclear Medicine

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Purpose: In PACS (Picture Archiving and Communications System) environment, the export of DICOM portable data for imaging (PDI) has been increased in accordance with the demands of patents referring to other hospitals. The DICOM PDI currently stored in a CD (Compact Disk) causes the problems of retrieve and archive occasionally in PACS environment of destination hospital although it was created under obeying DICOM standards. **Method and Materials:** DICOM validation toolkit was developed for verifying the DICOM data sets complying with the DICOM standard PS 3.3 to improve compatibility between the DICOM PDI and multi-vendor PACSs. The interoperability of problematic PDI in nuclear medicine imported to Yonsei University Medical Center in Seoul, Korea was evaluated through validation of DICOM CD data using the DICOM data validation toolkit. The evaluated PDIs were 5 NM (Nuclear Medicine) series and 10 PT (Positron Emission Tomography) series. **Results:** The main factors of the problematic NM PDI are that series number, content data, and content time presented null value and detector vector had no tag. As for the problematic PT PDI, series number presented null value, pixel aspect ratio had no tag, and both of image orientation and image position had no any values for VM=3 and VM=6 defined by DICOM standards. **Conclusion:** The DICOM data validation toolkit is expected to play an important role in validation of problematic PDI for patients and hospitals. Evaluation of problematic PDI will enable to bring the feedback of incompatibility to PACS vendors and PACS operating team in hospitals to improve interoperability of PDI.

SU-FF-I-52

Quantitative Assessment of Physical Characteristics of Laser and CCD Film Digitizers in PACS Applications

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Purpose: We quantitatively assessed the spatial resolution, contrast, and image uniformity of the laser and CCD film digitizers in PACS applications for our Hospital. **Method and Materials:** The modulation transfer function(MTF) was measured by using the created chessboard-pattern test film to obtain the edge spread function(ESF) for both of horizontal and vertical scanning direction. The line spread function(LSF) was obtained from the ESF results. A step wedge test film was created in order to evaluate the contrast characteristics. Optical densities(ODs) for each step-wedge region were measured using calibrated densitometer(x-rite, USA). Those values were grouped with the corresponding film OD values. To measure the accuracy of pixel value distribution in proportion to the distance from center of the film, we also created the uniformity test film which was quartered with different OD values for each quarter. All test films were digitized using both LASER (Model 2905, Array Corp.,Japan) and CCD-based unit (SEDAS Media Film Scanner,Kodak,Japan). **Results:** Spatial resolutions of the laser digitizer for both horizontal and vertical directions were 4.06±0.32cycles/mm and 4.24±0.20cycles/mm, respectively. However, those of the CCD digitizer were 2.06±0.33cycles/mm and 2.06±0.19cycles/mm at 10% of MTF. No differences in resolution were found with respect to location on the film. Contrast results were determined by means of useful OD range. Those values for the laser and CCD digitizer were 0.2~2.8, 0.8~2.8., respectively. The image uniformities of laser digitizer were 99.9, 99.4, 97.9, and 82.7%, where the corresponding ODs of the quarter were 0.2,0.7,1.4,and 3.1,respectively. However, those were 94.4,75.6,62.9,and 53.7% in CCD digitizer. **Conclusion:** In conclusion, laser digitizer can provide relatively higher resolution, wider useful OD range, and especially better image uniformity. Besides, because relatively low image uniformity of CCD digitizer may be caused by distribution of brightness of backlight, additional study for this aspect is necessary in further study.

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SU-FF-I-53

The Impact of Portal Imager Shifts and the Assumption of Rigid Isocentricity On Megavoltage Cone Beam CT Images

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Purpose: Linear accelerators and the current flat panel positioners do not represent a rigid isocentric imaging system. To correct for this effect in the reconstruction process of Megavoltage Cone Beam CT, the group uses projection matrices that are obtained from geometric calibration. This project studies the effect of deviations in detector position from the calibrated geometry which may occur over time. **Method and Materials:** To simulate the effect of portal imager shifts, we translated projection images before performing the reconstruction. Synthetic projection matrices that assume perfect isocentricity were also produced to study the utility of our geometric calibration. To accentuate the observed effects, we first used noise-free simulated projections of a CT phantom as well as reconstructions of small, high-contrast ball bearings. We also acquired anatomical images of a Rando head with an acceptable clinical dose (8 MU) to verify our capacity to identify the previously observed artifacts. **Results:** A pure flat panel shift of 2 mm along the longitudinal direction causes the same shift in the reconstruction volume. A 2 mm shift in the lateral direction however, greatly degrades the image quality with streaking and half-moon shadow artifacts. The orientation of those artifacts depends on the start and end angle of the acquisition. Since most of the flat panel flex was previously measured to be in the longitudinal direction, the use of synthetic projection matrices caused a blurring of the image in the longitudinal direction. **Conclusion:** The calibrated projection matrices play an important role at conserving the image quality around high contrast objects. A 2 mm lateral shift away from the calibration will likely be detectable in high contrast regions of anatomical images. Longitudinal shifts will not degrade the image but will cause a positioning error. **Conflict of Interest:** This research is supported by Siemens OCS.

SU-FF-I-54

Some Physical Factors Which Affect the Patient Doses and the Radiological Images Quality

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Purpose: The purpose of this paper is the analysis of the console set parameters, the shape and the composition of the X-ray spectrum that is generated by the Roentgen device and the estimation of the organ doses and the effective dose involved in several radiological examinations using Monte-Carlo simulations. **Method and Materials:** The quality of X-ray beam, is usually expressed in terms of HVL. The HVL method consists in several measurements of the radiation dose, free in air, using a set of aluminum filters and a RADCHECK 06-256-dosimeter. First, a spline interpolation on the mmAl-dose plot has been made. Then, the HVL1 (the added filtration that correspond to the dose reduction by 1/2) and QVL (quarter value layer, which is the added filtration that correspond to the dose reduction by 1/4) factors are estimated by solving the corresponding cubic spline equations using the classical Cardano formulas. The HVL2 factor is calculated as HVL2=QVL-HVL1. **Results:** For comparison, the theoretical values at the same settings, regarded as those values corresponding to an adequate radiological device, HVL1 and HVL2 were computed, using the XCOMP5R software provided by University of Vienna. The effective dose was calculated, using the PCXMC, a Monte-Carlo based software, provided by STUK (Radiation and Nuclear Safety Authority in Finland). HVL and homogeneity factor values for theoretic and experimental mode are presented below (mmAl)

	HVL1	HVL2	HVL1/HVL2
Theoretic	2.64 +/- 0.13	3.97 +/- 0.20	0.66+/-0.05
Experimental	2.09 +/- 0.10	2.46 +/- 0.12	0.85 +/- 0.06

Conclusion: The experimental HVL1 and HVL2 values are significant smaller then the theoretical values. that, all console set parameters are correct, we can conclude that patient doses should be greater then the corresponding doses generated by an appropriate X-ray device, due to the strong photons absorbtion at low energies.

SU-FF-I-55

Quality Control in Mammography Screening

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Purpose: The Romanian legislation in nuclear field regarding radiological protection of persons in the case of radiation medical exposures introduces the obligatorily implementation of QA programs in radiological practice. In this context, AIHA had a significant role receiving a grant from the Susan G. Komen Breast Cancer Foundation to implement Mammography Training Program in Romania. In this paper, the first results of the application in Romania of European protocols for QC of mammography screening in two representative mammography facilities in Cluj-Napoca (Institute of Oncology and Clinic District Hospital) are presented. **Method and Materials:** Between the several components of mammography system the QC was focused on the crucial elements such as the film processing and the basic performance of X-ray equipment (screen-film contact, phantom images, automatic exposure control system performance and AEC reproducibility, X-ray beam quality, average glandular dose and radiation output rate). The applied methodology is in accordance with ACR Mammography Quality Control Manual (1999). **Results:** Characteristic parameters of mammographic and automatic processing units was compared with limiting values given by International Protocols or with the permissible ranges calculated in advance. If the test results fell outside the action limits, the source of the problem had been identified and corrective actions had been taken. The worst deficiencies found in the equipment were related to AEC system and density control setting. **Conclusion:** The result of this survey shows that QC procedures have a positive effect on the performance of mammography X-ray equipment and on the production of high quality images. This minimises the possibility of repeating exposures and hence the patient dose. Practical application of such QC program in Romania impose the raise of medical physicist role in clinical activities and the assurance of qualitative service for X-ray equipment.

SU-FF-I-56

Smart Fiduciary Plate for Port Films in RT

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Purpose: New plate is devised to determine the geometrical information such as gantry and collimator rotations in weekly port films in routine radiation therapy. **Method and Materials:** : The plate consists of a base plate, an orientation marker, and scales. The base plate is made of 2cm acrylic plate and is inserted into the blocking tray slots of linear accelerators. It has three unique features: (1) two-step wedges are implemented on one side of the plate, thus, making easy inserting and removing the plate into or from blocking tray slot. (2) Special geometrical structures of 4 major axis and vertical/horizontal lines (1mm wide * 18mm long) are made in grooves in the base plate and the Lipowitz metal is injected into the grooves with the use of high -pressure pump. (3) The orientation maker is made of two cylinders , and one cylinder is situated on top of the other. The volumes of two cylinders are exactly the same, but the central portion of one cylinder is blocked. The half of two cylinders is filled with mercury or fine lead grains mixed with saline water. **Results:** : The plate can be positioned with the uncertainty of < 0.2mm with 2 set-wedge structures. Because of the gravity effect, the shadow of the orientation marker has very unique shapes in the port film for various gantry and collimator rotation. The geometrical relationships between the marker and the various lines are unambiguously analyzed and provide the mechanical information such as gantry and collimator rotations, which are very critical in radiation delivery of 3D CFRT **Conclusion:** : This plate has been used for weekly port film for several years. It is very effective tool as a port film QA in routine RT, 3D CFRT as well as mechanical QA for multi-lead collimators.

SU-FF-I-57

Improvement of Osteoblastic Metastases Diagnosis From Skeletal Digitized Radiographs

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Purpose: To evaluate the diagnostic usefulness of a method based on gray level parameters to distinguish between skeletal digitized radiographs of healthy bone and osteoblastic metastases. **Method and Materials:** The authors previously developed an automated computerized scheme in order to characterize healthy bone on digitized radiographs (DR). We obtained an optimized healthy bone classification to compare with pathological bone: cortical (CO), trabecular (TR) and flat (FB) bone. In the present study, 35 osteoblastic metastases DR (size of 0.175-mm pixel and 4,096 gray levels) were classified in non flat bone (OM1) and flat bone (OM2). The parameters calculated were: mean, standard deviation and coefficient of variation (MGL, SDGL and CVGL) based on gray level histogram analysis. Diagnostic utility was quantified by measurement of parameters on healthy and pathological bone DR, yielding quantification of area under the ROC curve, Az. **Results:** All three image parameters show high and significant values of Az when comparing TR and OM1, showing MGL the best discriminatory ability (0.972). In reference to flat bones, MGL do not show any diagnostic capacity between healthy and OM2 groups (0.497), but this goal can be satisfactory achieved using SDGL or CVGL both showing a similar diagnostic ability (0.851 and 0.828 respectively). **Conclusion:** Our results confirm that this method is useful for differential diagnosis between healthy bone and osteoblastic metastases on skeletal DR. **Conflict of Interest:** Supported in part by "Fundació Universitària Agustí Pedro i Pons" University of Barcelona.

SU-FF-I-58

Effects of Prepatient Filtration On Contrast, Scatter and Dose in CR Chest Exams: A Phantom Study

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Purpose: To establish a convenient method for objective comparison of the consequences of exposure conditions and filtration on image quality and patient dose in adult and pediatric thoracic computed radiography (CR) examinations. **Method and Materials:** Computer simulation (MATLAB) was utilized for approximating the x-ray spectrum and its modification by pre-patient filtration, predicting the attenuation by the phantom, predicting pixel values in the CR image, calculating expected contrast-to-noise ratio (CNR), and estimating patient dose. CDRH LucAl Chest and Pediatric phantoms with the Al quality insert were imaged at 125 kVp with beam filters (Z=29, 57, 75) with a grid and 75 kVp with beam filters (Z=13, 29, 50) tabletop, respectively. Entrance Skin Exposure (ESE) and detector exposure were measured. Fuji FCR 5000 CR images were developed with L=4 in fixed EDR Mode. Pixel ROI and SD were extracted from DICOM images. Doses were estimated by calculating absorption of the attenuated spectra in water of 20 cm (adult) and 10 cm (pediatric) thickness. Scatter-to-primary ratios (SPR) were estimated for each case using beam blocks. **Results:** Filtration increased half-value layer (HVL) reducing ESE and contrast. Contrast-to-Noise Ratio (CNR) can increase, depending on Z and the thickness of the filter. The same CNR produced by the unfiltered beam using Automatic Exposure Control (AEC) can be accomplished at 23% lower ESE. Even with a lower ESE, higher HVL increases exposure-to-dose conversion, resulting in higher dose absorbed by the patient to produce the same receptor exposure. No filtered case had CNR superior to the unfiltered case at the same patient dose. SPR also increased with filtration. **Conclusion:** LucAl Chest and Pediatric phantoms provide standardized platforms for investigating effects of exposure conditions on image quality and patient dose in digital chest radiography. Filtration can provide identical CNR at lower ESE, but may also deliver higher patient dose.

SU-FF-I-59

MTF Measurement of Digital Imaging Systems Used In Radiotherapy-

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Purpose: The pre-sampled MTF was used to investigate the resolution of a storage phosphor plate. Three commercial computed radiography (CR) cassettes (Kodak EC-L fast and regular, and Agfa fast) were used. The MTF of the CR system was compared to the MTF of an electronic portal imaging device (EPID) system. **Method and Materials:** The MTF was measured using the edge method. For kilo-voltage simulation images, the edge device was a 180x100x2 mm^3 lead plate with a 104 mm polished edge, and the standard spectrum (RQA3) and geometry specified in IEC 62220-1 were used. The edge device for 6 MV portal images was a 75x50x50 mm^3 lead block with one of the 75x50 mm^2 surfaces polished. A new method based on multiple over-sampled edge profiles was developed to verify the edge angle determined by the other two methods, which were based on edge detection techniques. The line spread function was calculated by the finite-element difference method and then Fourier transformed to obtain the MTF. **Results:** For simulation images: the MTFs obtained with the Kodak regular cassette were slightly lower than those obtained using the two fast cassettes. The MTFs in the line scan direction fell off slightly faster than those in the perpendicular direction. The MTFs obtained with large and small pixel sizes were almost identical. For the portal images: the MTFs for the EPID and CR systems were similar at frequencies lower than 0.4cycles/mm. **Conclusion:** Although the cassettes were designed for film use, the fast cassette allows exposure reduction for the use of CR plates, and results in slightly better MTFs. For CR systems, the laser spot size remains the same regardless of the pixel size, so changes in pixel size have little impact on the MTF. The smaller-pixel-size CR system gives better MTFs than the EPID system.

SU-FF-I-60

Image Quality Improvement Using a Custom Ventilator for Respiratory-Gated Micro-CT

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Purpose: Acquiring Micro-CT images of murine lungs *in vivo* requires respiratory gating to achieve optimal tissue contrast at full inspiration. The use of a custom small-animal ventilator and a specific acquisition technique has resulted in a dramatic improvement in image quality. **Method and Materials:** A commercially available small animal ventilator was customized for use with our commercially available micro-CT scanner. The modified ventilator can hold the pressure in rodent lungs at a constant level (essentially perform a series of short breath-holds at full inspiration), and can be programmed to trigger the scanner acquisition phase. The ventilator is set to cyclicly achieve a pre-set pressure level of the anesthetic gas mixture (inspiration), trigger the x-ray on phase of the scanner, acquire a single frame during the stable pressure phase, close the x-ray shutter, and finally release the pressure of the anesthetic gas mixture (expiration) while the scanner rotates to the next view position, at which point the cycle repeats. Images can be reconstructed with either 90 or 45 micron isotropic voxels. Example images of several mice with lung tumors will be presented. Radiation dose is estimated to be about 0.26 Gy per scan session using this methodology. **Results:** This implementation has produced images with improved visibility of the tissue components, including airways and pulmonary blood vessels. The margins of individual lung lobes can be identified, which is very helpful when determining the location of a pathologic structure (lesion) for research purposes or subsequent necropsy. The improved image quality is also very helpful in the detection of small (0.3-0.5 mm diameter) lung lesions. **Conclusion:** Lung cancer research can benefit from extensive use of mouse models to investigate potential new treatment approaches. The use of improved non-invasive imaging has positively impacted our lung cancer research program.

SU-FF-I-61

A PC-Based 3-Dimensional Ultrasound Software Package

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Purpose: Although ultrasound imaging is integral to a number of applications (such as prostate localization during radiation treatment and thyroid cancer screening in remote counties), portable ultrasound units lack 3-dimensional (3D) image display, thus limiting the usefulness of the imaging modality. The purpose of this study was to design and test a freehand 3D image processing and visualization software package, Ultra3D, to work with an existing ultrasound unit that lacks 3D capability. **Method and Materials:** The Ultra3D system was designed to work with any ultrasound units, especially the laptop-PC based Terason Smart Probe. The Ultra3D software system is mainly composed of two components: the user interface developed with Visual Basic and the Image Processing and Visualization library (IPVL) developed using Visual C++. The Ultra3D package has four major functions: image acquisition, 3D image reconstruction, image preprocessing, and 3D visualization. When the

software is integrated with the Terason SmartProbe™ system, a series of 2D images is captured using free-hand scanning method. These 2D images are then registered at different viewing angles, and their composite images are displayed by different volume and surface rendering techniques. Automatic 3D segmentation allows the interested regions to be better visualized. **Results and Conclusion:** This Ultra3D system has been successfully integrated with many different ultrasound units. The integration with the laptop-PC based Terason Smart Probe allows 3D image manipulation to be possible at restricted working environments that require portability and user-friendliness. 3D image processing and visualization show that, this program, with a digital image-capture system, a semi-automatic contours highlight method, and variant volume rendering techniques, greatly speeds up the reconstruction and visualization process, and gives the doctor more intuitive images. Future efforts include application of the system for prostate localization during radiation treatment and thyroid cancer screening in remote counties.

SU-FF-I-62

Planning Image-Guided Endovascular Interventions: Models to Determine Point-Specific Vessel Tortuousity

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Purpose: Clinicians often have difficulty passing guidewires and stents during endovascular interventions. Therefore, we are developing models to assess the access path based on stent as well as vessel dimensions. **Method and Materials:** Multi-view images of the carotid are acquired during clinical endovascular interventions. The vessel centerlines in the images are indicated and fit with splines. The vessel sizes are measured in the images. The multi-view imaging geometry is determined using the vessel information, and the three-dimensional (3D) vessel centerline is reconstructed using epipolar constraints. The vessel lumen is generated using the measured sizes and a circular cross-section model. Simulated models of devices are created and passed through the 3D patient-specific vessel. The models for this study included (a) a two-segment flexing device centered on the centerline, (b) a four-segment flexing device centered on the centerline, and (c) an unbound six-segment flexing device. The models were placed at all points along the vessel length and the point-specific tortuousity was calculated at each point. The tortuousity was calculated (a) as the ratio of the device length divided by the maximum length of the device inside the vessel, (b) and (c) as the inverse of the cosine of the average angular deviation from a straight device while keeping all segments inside the vessel. **Results:** The tortuousities calculated for each model are in good agreement with the apparent tortuousity of the vessel, with tortuousity decreasing from models one through three, reflecting the increased flexibility of the stent model. **Conclusion:** These models should provide the basis for more accurate assessment of the passage of devices through access vessels and perhaps be useful in decisions regarding stent lengths and flexibilities.

SU-FF-I-63

Reproducibility of Guidewire Positioning and Stent Path for Endovascular Interventions

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Purpose: Clinicians often have difficulty passing guidewires and stents during endovascular interventions. As a first step toward facilitating guidewire and stent guidance, we have investigated the reproducibility of paths that guidewires and stents take as they pass through the access vessels. **Method and Materials:** An internal carotid vessel phantom having tortuousity similar to the carotid siphon was constructed from 3 mm tubing and encased in Sylgard elastomer. A guidewire was repeatedly passed through the phantom. Each time, images were acquired for several views (9" II mode, 225 micron pixel size). In addition, an undeployed stent (length 30 mm, diameter 1.3 mm) was repeatedly passed over the guidewire while images were acquired at 10 fps again using different views, without repositioning of the guidewire. Pairs of views (0° LAO, 82° LAO) were selected for biplane reconstruction. The centerlines of the guidewire were manually indicated and fit with a spline in each image. The correspondence between the indicated centerlines is established using the epipolar constraints, and 3D centerline of the guidewire and stent path were reconstructed. The reproducibility of the guidewire and stent positions were then determined after aligning the images (to remove jitter) and the 3D centerlines. **Results:** The average repeated-indication difference for the guidewire was 0.4 ± 0.1mm (2D) and 0.5 ± 0.1mm (3D). The average repeated-positioning difference for the guidewire was 0.4 ± 0.2mm (2D) and 0.4 ± 0.1mm (3D). The average guidewire-versus-stent-path difference was 0.5 ± 0.2mm (2D) and 0.4 ± 0.04mm (3D). **Conclusion:** Guidewire positions are very stable, and stent passage appears to affect guidewire position near the vessel wall, indicating that physical/mechanical models may be used to determine guidewire and stent-pathways.

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SU-FF-I-64

X-Ray Micro-Angiographic and Fluoroscopic Image-Guided Localization of Asymmetric Endovascular Stents (AES): Study of Accuracy Versus Exposure

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Purpose: Image-guided neuro-endovascular interventions, such as treatment of intracranial aneurysms using asymmetric endovascular stents (AES), can be lengthy procedures with high patient dose, yet the treatment success may be highly dependent upon the accuracy of placement of the AES at the aneurysm to occlude the orifice. We investigated the variation of AES localization accuracy for angiographic to fluoroscopic exposures using a high-resolution micro-angiographic (MA) system described previously. **Method and Materials:** We acquired a sequence of images of a simulated AES placed in a head-equivalent phantom for different calibrated orientations every two degrees. We tracked the 150 μm gold-sphere AES markers with images acquired using the MA detector with 43 μm pixels in angiographic mode and a detector exposure of 1.2 mR/frame. The MA detector uses a fiber-optic taper to optically couple an x-ray converter phosphor to a high performance 1024x1024 matrix CCD camera to enable imaging over a region of interest at the interventional site. Lower dose acquisitions corresponding to fluoroscopy were simulated by adding various amounts of Gaussian noise to achieve a SNR range from ~80 to 8 corresponding to a 100X reduction in dose. The AES marker position determined by software image analysis was plotted vs. known rotation angle. An inverse function was fit, and the fit residuals calculated in degrees to gauge localization inaccuracy. **Results:** The results indicated that the accuracy of the stent placement was maintained within 6 degrees for an SNR between 79 and 22. However, for a SNR below 10, the stent localization accuracy deteriorated to 30 – 40 degrees. **Conclusion:** Intervention using AES with radio-opaque markers can be done at fluoroscopic dose rates during the initial part of the procedure followed by higher exposures to accurately guide the final stent orientation during deployment.

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SU-FF-I-65

A Diagnostic X-Ray Simulator for Out-Patient-Department Examinations

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Purpose: To develop a diagnostic X-ray image simulator for commonly used out-patient-department examinations including lower extremities, skull, abdomen, pelvis, chest, and spinal cord. This simulator can be used as a computer-assistant-teaching software for training technologists more familiar with the relationship between image quality and operation conditions. **Method and Materials:** A detailed simulation of a diagnostic X-ray image requires four major inputs: operation conditions, X-ray spectral and spatial distributions, a human model, and cross-section corresponding to different materials. This study has collected commonly used operation conditions such as kVp, mAs, SSD for different OPD examinations. These conditions have been inputted to a Monte Carlo code, BEAMnrc, to build a virtual X-ray machine for calculating X-ray spectral and spatial distributions. After that, a high resolution voxelized human

model, VIP-Man constructed from segmented Visible Male Dataset, will be imaged with this virtual X-ray machine. The cross-sections of different materials are generated by PEGS4, a cross-section preparation tool come with EGS4. **Results:** X-ray spectra simulated using BEAMnrc is almost identical to those listed in literatures, or from a spectra simulator, XCOMP3; except there is about 30% underestimation in characteristic peaks. However, this underestimation will lead to less than 0.1% deviation in our simulation. Heel effects can be observed in our simulated images. The intensity response was calibrated to a real digital X-ray machine, and point spread functions of this machine are measured to degrade our simulated images. **Conclusion:** We have developed this X-ray image simulator which can benefit the training of technologists. This simulator can be further improved to serve as a platform for studying image quality parameters such as QDE or MTF after we adding more realistic model of image receptor.

SU-FF-I-66

A Method for Validation of Image Fusion Software for PET and CT Coregistration for Brain Radiotherapy

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Purpose: A technique is described to quantitatively evaluate several methods for coregistering PET and CT images: 1) manual registration based on fiducial markers, and 2) automated registration using several commercial algorithms that maximize mutual information. **Method and Materials:** CT and PET scans of an Alderson Striatal head phantom were obtained with and without three rectangular fiducial markers (1 mm × 1 mm × 3 mm). Each marker contained 10 μCi of Na-22 along with contrast agent so markers were visible on both CT and PET scans. Several CT scans were acquired with a pixel size of 0.7 mm × 0.7mm of the phantom rotated by known amounts along the principle axes. PET scans were obtained at two resolutions, 2 mm× 2 mm and 4 mm × 4 mm pixels, at a single orientation (supine, zero rotation). For these scans the main compartment of the phantom was filled with F-18-FDG at clinically-observed concentrations. Transmission scans also were obtained. **Results:** The accuracy of both automatic and manual coregistration of the emission PET to the CT was evaluated by comparing the transformation matrices (TM) to the known displacements. Image fusion between different CT and the PET scans show TM within 2-4 degrees of the known rotation for manual fusions and 1-3 degrees for automated registration. A subjective qualitative evaluation of the results based on the structures in the phantom and intensity pattern showed agreement to within 2 mm for higher resolution PET scans. Results were similar for registration of the transmission PET to the CT. Because these results are based on rigid-body motions, they establish an upper-bound on the accuracy obtainable from these registration techniques. **Conclusion:** A method has been developed to assess and quantitatively evaluate image coregistration software for CT and PET images.

General Poster Discussion
Exhibit Hall 4A
Joint: Imaging and Therapy

SU-FF-J-01

A Comparision of 4DCT with Breath-Hold CT for Determination of Tumor Motion with Respiration

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Purpose: Internal target volumes (ITVs) have been determined using both breath-hold CT scans (BHCTs) and four-dimensional CT (4DCT) to assess the extent of tumor motion during normal respiration. The purpose of this work is to compare the differences in tumor excursion when measured with BHCT and 4DCT. **Method and Materials:** All 4DCT and BHCT datasets in this study were acquired as a part of the radiotherapy simulation process using a commercial 4DCT system (Discovery ST, GE Healthcare, Waukesha, WI). Respiratory tracking was accomplished using a commercial system (RPM, Varian Medical Systems, Palo Alto, CA). A visual prompt from this system was displayed to patients to assist them in holding their breath at the correct level during BHCTs. The locations of the tumors with respect to a reference dataset (4DCT end-expiration) was determined using a rigid-body cross-correlation algorithm that found the location on each dataset that best matched the region of the physician-determined gross tumor volume (GTV) on the reference dataset. The patient did not move between the 4DCT and BHCT scans, thus differences in tumor location were due to tumor motion rather than bulk patient motion. **Results:** For 20 patients, the average difference in displacement of the GTV between BHCT and 4DCT scans was 5 mm at end-inspiration and 3 mm at end-expiration with maximum differences of 12 mm and 10 mm respectively. GTV motion on BHCTs was always greater than or equal to the motion on the 4DCT. The direction of tumor motion was also found to be different between 4DCT and BHCT images with the average difference in the vector angles being 14^{o}. **Conclusion:** The results of this work suggests that patients being treated during normal breathing should be simulated during normal breathing (4DCT) and those to be treated using a breath-hold technique should be simulated using BHCT.

SU-FF-J-02

A Comparison of Amplitude- and Phase-Based 4D CT

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Purpose:
Four-dimensional (4D) CT depends on accurate correlation between temporally acquired CT slices and the patient's respiratory cycle. One approach is to record the position of an external marker placed on the abdomen or chest during the scan, and retrospectively match the CT data with the phase of the marker motion. While very effective for regular breathing patterns, the phase-based approach can lead to significant mismatch between adjacent image segments when the respiratory motion exhibits irregularities. We propose a method of extracting amplitude-based 4D CT from cine-acquired CT data sets, and compare the amplitude-based 4D CT with the phase-based 4D CT for both phantom and patient data. **Method and Materials:** CT data sets were acquired in cine mode on the GE Discovery ST, and motion of an infrared reflecting block was recorded using Varian's Real-time Position Management (RPM) camera. Rather than use the phase-based calculations of the RPM system, we replaced the phase field with pseudo-amplitude values spanning the full respiratory cycle (i.e., differentiating inspiration from expiration). The modified respiratory trace file was then sent, along with the cine CT data, to the GE Advantage Workstation for processing. The method was applied to a thoracic phantom moving irregularly in the longitudinal direction, and to an abdominal 4D scan of a lung cancer patient. **Results:** For both phantom and patient data, the phase-based 4D CT images showed boundary mismatches of up to 1 cm between couch positions. The mismatch on the amplitude-based sets, however, was less than 2 mm throughout the field of view. **Conclusion:** Phase-based 4D CT can lead to mismatched slices when the respiratory cycle involves irregularities. In such situations, by replacing phase with a modified definition of amplitude that distinguishes inspiration from expiration, a substantially improved 4D CT image can be generated.

SU-FF-J-03

A Dynamic Phantom for 4-Dimensional Imaging and Radiation Therapy Verification

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Purpose: Current research is producing a variety of methods to model breathing motion in the abdomen and thoracic regions. Testing of these methods is hampered by the lack of a reproducible standard that reproduces complex, multidimensional motion. The purpose of this study was to create a 4D phantom that could be used for evaluation of breathing motion. **Method and Materials:** A 4-dimensional (4D) stage capable of arbitrary multidimensional motion with speeds up to 10 cm/sec was constructed. The positioning system was developed using stepping motor-actuated linear slides (Velmex Inc.) capable of carrying a 10 kg water-equivalent phantom. A 4 axis motor controller (National Instruments) with onboard PID algorithms was used with an amplifier capable of 4 Amps per axis at 1.7 V (Primatics, Inc). Custom software was written to allow input trajectories as a text file of x, y, and z coordinates spaced 20 ms apart. A 3 Dimensional digitizing arm (Immersion Corporation) was physically connected to the system to monitor stage localization accuracy. The intended position and measured positions were compared over a series of points. **Results:** The

scanning system produced highly verifiable and reproducible trajectories for a variety of ellipses and modeled tumor trajectories. The system also produced very accurate and precise positioning using simple raster scanning patterns. The average error was 0.1397mm, where the published error for the digitizing arm is 0.3mm. The total cost to construct the phantom was less than $10,000. **Conclusion:** The 4D phantom produces accurate positioning throughout the range of motion found in human tumors. It can provide a 'gold standard' for evaluating 4D CT, organ motion, and internal localization systems for both research and clinical applications. Further refinements, such as the addition of encoders for truly closed loop motion control, are ongoing.

SU-FF-J-04

A Method to Model 4D Organs for Monte Carlo Radiation Dosimetry

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Purpose: The objective of this study is to construct a detailed 4D standard patient testbed for studying effects of organ motions on treatment planning. **Method and Materials:** Segmented Visible Human images, containing 80 organs and tissues defined in a 3D static model called VIP-Man, were combined with Non-Uniform Rational B-Splines (NURBS) and clinically obtained respiratory motion data to deform the surfaces of the lungs. Deformable image registration was performed to establish correct spatial definition of the organ boundaries. A lesion in the left lung was simulated. The 4D model containing 3D anatomical information for each of the eight simulated motion phases was then re-voxelized before being defined in the EGS Monte Carlo code. A hypothetical 3D static treatment plan for the lung lesion was considered in the Monte Carlo simulations. **Results:** Normalized doses to the lesion are plotted for each of the respiratory phases. It has been found that the lesion could be under-dosed by as much as 40% for different respiratory phases and for the irradiation conditions considered in this study. Although more analysis is underway, this study clearly demonstrates that the motion of the organs can be accurately modeled and implemented in the Monte Carlo code for 4D dose calculations. **Conclusion:** A partial-body 4D VIP-Man model has been developed using the NURBS and clinical respiratory data, and implemented into the EGS Monte Carlo code for dose calculations. The detailed anatomical information in this 4D model makes it a very convenient research tool to study radiation treatment planning and medical imaging involving moving organs and tissues. This study also identified issues to be further addressed for routine clinical research and applications. The procedures can be extended to patient specific models constructed, for example, from multi-slice CT data.

SU-FF-J-05

A Novel 4-D CT Acquisition Protocol to Validate Respiratory Gating with the RPM System

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Purpose: To introduce a method in acquiring a 4-D CT data set without the use of external markers, to validate the use of the RPM Gating System, and to present the results from the first lung cancer patient treated with this method. **Method and Materials:** Patients were scanned on a GE Multi-Slice CT Scanner. Registration of the images was based on internal correlation at tissue interfaces between successive respiratory phases. This resulted in a 4-D CT data set acquired without the use of external markers. Regions of interest (ROI) were also constructed on an axial CT slice containing the chest wall, the tumor, and any other critical structure that was affected by respiratory motion. The mean CT number in each ROI was plotted as a function of mid-scan time. The RPM signal was also plotted over the same mid-scan time interval and the sample correlation coefficient, r, of each ROI and RPM curve was determined. **Results:** 4-D CT improved the quality of images affected by respiratory motion. For our first patient treated, the sample correlation coefficient was calculated for all combinations of the tumor, chest wall, liver, and the signal acquired by the RPM and the magnitude ranged between 0.897 and 0.982. This suggested that the RPM could predict tumor/internal organ motion determined by the 4-D CT data set. Electronic portal images were taken at the treatment phase and matched well with digitally reconstructed radiographs taken at the same phase. Portal images of the posterior field used in treatment were also taken in cine loop format during three different treatment fractions throughout treatment and showed no changes in anatomy at the treatment phase over the treatment period. **Conclusion:** The RPM system is an effective tool for respiratory gating if treatment planning and verification is based on 4-D CT.

SU-FF-J-06

Analysis of Periodicity and Complexity of Breathing Patterns for Radiotherapy

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Purpose: Existing models of breathing generally use a simple modified cosine function, which poorly approximates true breathing patterns. This study pursues a more robust means of quantifying the periodicity and variation of individual breathing patterns. **Method and Materials:** The problem is formulated as a multilayer optimization problem where a search over all possible periods for the "best-fit" signal is conducted. For each period within a reasonable range, a subspace of all signals with that period is constructed and the observed breathing trajectory is projected onto that subspace to obtain the closest matching periodic signal. Projections from each such subspace are then compared to yield the overall best periodic approximation. Temporal sampling is taken into account explicitly in the derivation so that the optimal period is not restricted by the sampling rate of observed trajectory. Utilizing a projection method, a closed form solution is derived, resulting in an extremely computationally efficient algorithm. Performance was assessed with clinical RPM and diaphragm trajectory data. **Results:** Experiments with clinical data yield "best" periods between 3-10s for normal breathing, agreeing with physical understanding. Unlike traditional Fourier transform based approaches, fundamental patterns and approximation errors are obtained. These patterns yield a richer (yet physically sound) class of shapes than the commonly employed heuristic modified cosine. Approximation error of the optimal projection signal agrees with intuitive explanation of regularity, i.e., the error monotonically increases with the irregularity level.

Conclusion: This work provides a potential irregularity measure for periodicity that would facilitate individualized treatment planning. The approximation error serves as an index for variation in breathing pattern, and thus helps to determine the necessity of an individualized treatment plan. Understanding optimal periods and fundamental patterns of breathing would help in designing a patient/fraction dependent treatment plan.

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SU-FF-J-07

Analysis of Response Time Delays in An Adaptive Feedback System: Considerations for a Real-Time Intra-Fraction Motion Tracking Couch

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Purpose: To assess the impact of response time delays in an adaptive feedback couch-based respiration-induced motion tracking system. **Method and Materials:** We employed a convolution/superposition based Monte Carlo dose calculation to determine the impact of response delays between the tumor or surrogate respiration markers and the couch on planned dose distributions. The isocenter was randomly sampled from the distribution of the residual tumor/marker/couch trajectory. With this calculation we obtained the ensemble average over all possibilities of the dose distribution (assuming each fraction starts with a random respiration phase). Two test motion trajectories were used: 1) sinusoidal and 2) a published diaphragm motion description. For motion periods of 3 and 4 s and a motion amplitude of 1 cm, we simulated response delays ranging from 100-500 ms. Calculations were validated with measurement for one case. **Results:** For a motion period of 3 s, the penumbra width increased by 1-11.5 mm when superior-inferior motion with an amplitude of 1 cm was considered for response delays ranging from 100-500 ms with slightly worse results observed for the published motion trajectory. The decrease in the width of the 90% isodose line was 1.2-16.7 mm. The degradation in the penumbra and 90% isodose line width in the direction of motion were less severe when the motion period was 4 s. Phase delay film measurements agreed with our calculations to < 2 mm agreement of the corresponding

isodose lines. **Conclusion:** For both sinusoidal and a published diaphragm motion trajectory, a response time of < 300 ms within the feedback loop is desirable to deliver highly conformal plans reliably. Response times of 500 ms or higher are equivalent to applying no real-time motion compensation and in some cases can degrade the plan much worse than no corrective action.

SU-FF-J-08

Calculating Biological Effective Dose in the Presence of Organ Deformation

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Purpose: Evaluate the total biologically effective dose (BED) delivered to the prostate over the course of treatment in ART, accommodating organ motion using deformable image registration. **Method and Materials:** Using an in-treatment-room CT-on-rails, scans are acquired on the first five days of treatment and twice weekly thereafter. For each daily image, large-deformation diffeomorphic registration is performed to determine, for each voxel in the planning image, the location of the corresponding volume of tissue on the patient at the time of a given fractionated treatment. Knowing its position at the time of treatment, it is possible to evaluate the dose acquired by that volume of tissue on the treatment day. These varying doses can be summed for each voxel, yielding a map of the total delivered dose.
However, this total dose does not correctly account for the cumulative radiobiological effect. To incorporate the fractionation biological effect, we use the Linear-Quadratic model. That is, for each voxel in the planning image, we accumulate the dose from each day, taking into account the quadratic dose response incorporating the tissue sensitivity (α/β) for the tissue type of the given voxel. This process yields a distribution of delivered BED. **Results:** For a series of patients we evaluate dose distributions and DVHs for planned and delivered BED using published values of α/β. These will be used to compare ART and standard IMRT treatment. Total dose and BED to the prostate are compared to the planned dose and BED, showing appreciable differences. **Conclusion:** Voxel-based radiobiological effects instead of voxel-based radiation dose should be accumulated in the fractionated treatment course for patients with organ motion and setup variation.

SU-FF-J-09

Comparison of Auto-Contouring with Manual Contouring: A First Step Towards Automated 4D Treatment Planning

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Purpose: Four-dimensional (4D) radiotherapy is the explicit inclusion of the temporal changes in anatomy during the imaging, planning and delivery of radiotherapy. One key component of 4D radiotherapy planning, is the ability to auto contour the individual respiratory phase CT datasets (up to ten in total) comprising a 4D computed tomography (CT) scan. A tool that can be used to automatically generate such contours (based on contours manually drawn on a single CT phase) is deformable image registration. The purpose of the current study was to compare automatically generated contours with manually drawn contours. **Method and Materials:** Two out of ten patient 4D CT data sets have completed this study. The 4D CT scans consisted of a series of ten 3D CT image sets acquired at different respiratory phases. Large deformable diffeomorphic image registration was performed to map each CT set from the peak-inhale respiration phase to the CT image sets corresponding with subsequent respiration phases. The calculated displacement vector fields were used to deform contours defined on the peak-inhale CT automatically to the other respiratory phase CT image sets. Auto-contouring was performed on each of the ten 3D image sets via automated scripts. Treatment planning system, Pinnacle version 7.7 was interfaced with automated scripts to view the resulting images and to obtain the volumetric and displacement information. **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. **Conclusion:** An automated system is established to auto - contour the ROI 's starting form the ROI's in the inhale phase to the other phases of the respiratory motion using Pinnacle Treatment planning system. Auto-contoured organs and the GTV in the Thorax agree with the manually drawn ROI's.

SU-FF-J-10

A 5-Dimensional Breathing Motion Model for Radiation Therapy

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Purpose: To develop a mathematical formalism that models breathing motion of lung tumors and normal organs for radiation therapy treatment planning. **Method and Materials:** The model is based on the assumption that breathing motion is caused by interactions between muscle-induced air-pressure distributions and the supporting structure of lung tissues. For quiet respiration, the motion of each object within the lungs is broken down into two independent components. First, the positions in the steady-state (zero airflow) are modeled as a function of breathing depth, parameterized by the tidal volume v. As the patient breaths deeper, the objects move farther along their trajectories. Second, the hysteresis commonly observed in lung motion is due to local pressure imbalances caused during the dynamic act of breathing and is assumed to be a deviation from the zero-flow trajectory. The hysteresis component is assumed to be proportional to local pressure imbalances which are proportional to the airflow at the patient's mouth, so this component is modeled as a function of airflow $f=dv/dt$. The motion of any internal object, therefore, has five degrees-of-freedom; the three Cartesian coordinates of the object during a user-selected reference breathing phase, the tidal volume and the airflow. **Results:** The model was applied using a linear mathematical form used with measured patient breathing-trajectory data of 76 tracked objects in 4 patients, which data was acquired using 4DCT and concurrent spirometry-measured tidal volume. The tracked-object displacement was a linear combination of two independent vectors with lengths proportional to the tidal volume and airflow. The patient data showed that the mathematical formalism was capable of modeling the objects' motion within 10% and 15% of the objects' maximum extent for 73% and 95% of the objects, respectively. **Conclusion:** This 5-dimensional model provides a method for mapping breathing motion and is being extended to more clinical datasets.

SU-FF-J-11

A Feasibility Study On Evaluation of Moving Phantom for 4D Radiotherapy

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Purpose: To develop the moving phantom for dosimetric and geometric evaluation of the 4D radiotherapy such as gated radiotherapy, breathing control radiotherapy and tumor tracking. **Method and Materials:** This system consisted of the software, the respiration monitoring mask (ReMM) and the moving phantom. Patient's respiration was measured with thermocouple installed in ReMM. The ReMM was connected directly to the operational amplifier. The respiratory signal was digitized by the data acquisition card in the computer. The program, which acquires and records respiratory signal and generates the digital signal to make the phantom simulate respiratory organ motion, was developed. The phantom moved by the servo motor, to which the program sent the digital signal. The respiration of three lung cancer patients, whose organ motion was greater than 5 mm, was monitored through ReMM and fluoroscopy simultaneously. While the phantom simulated patients' organ motion, its motion was monitored by RPM® to verify the effectiveness of the phantom. The discrepancies between the respiration curve and the organ motion and between the respiration and the phantom motion were estimated as standard deviations for each patient to evaluate the moving phantom. **Results:** Comparing with the curves of respiration measured by thermocouple and these of the organ motion measured by fluoroscope, the mean standard deviation of discrepancies was 9.68%. The standard deviation of the discrepancy between the respiratory curve and the organ motion was estimated at 8.52%. **Conclusion:** The patients did not complain about discomfort with the respiration monitoring mask. The phantom could simulate the organ motion according to the respiratory

signal from ReMM. It is expected that the simulating phantom could be used to verify the 4D radiation therapy.

SU-FF-J-12

Computed 4D Patient Models for Motion Compensation in Radiotherapy

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Purpose: We designed a system that can track tumors moving due to respiratory motion, allowing more specific and effective irradiation of the tumor. **Method and Materials:** First two CT scans are taken during maximal inhalation and exhalation. Then several synthetic intermediate scans are computed by using morphing methods, yielding a 3D motion picture. Before treatment x-ray images are taken periodically and compared to the 4D model. After registration of the x-ray with the model we know the best matching stack and therefore tumor position and respiratory state. Thus we acquire correlation from respiratory state to tumor position. Due to a registration time of 10 seconds for each stack, we only get intermittent information about the target location. The target may already have moved. Therefore we use an infrared tracking system, with emitters attached to significant positions of the patient's body, to report information on the current state of respiration in real-time. The information of the sensor is correlated to the target location computed by the comparison between the live shot and the model. **Results:** To create the model we use a thin-plate spline-based method. 47 corresponding control points were manually selected for deforming a lung. To evaluate the results transversal snap shots were compared with the model, yielding the corresponding respiratory state. We also tested the 2D/4D registration process by generating two mutually orthogonal DRRs, which we matched afterwards to the model. The best match was the stack containing the DRRs, furthermore the neighboring stacks led to the next best results. **Conclusion:** We have shown that it is possible to determine the respiratory state by matching a synthetic x-ray to a generated 4D model of an internal organ. Next steps will be to improve our method of generating the model and to test the registration with real x-rays.

SU-FF-J-13

Cumulated Fraction Effects On the Interplay Between MLC and Respiration-Induced Intra-Fraction Motion During Step-And-Shoot IMRT and Dynamic Arc Delivery

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Purpose: To investigate the cumulative MLC and respiration-induced tumor motion interplay effects over a multi-fraction treatment regimen for step-and-shoot IMRT and dynamic arc delivery. **Method and Materials:** Seven-field IMRT and nine-arc dynamic plans were used to test the interplay effects between the MLC and respiration-induced motion. Respiration-induced motion was simulated with a motion model consisting of a slide-table with a platform placed on top of the slide table. Phantoms were placed on top of the platform and ten film measurements were performed for sinusoidal motion in the superior-inferior direction and the medial-lateral directions with a motion amplitude of 1 and 2 cm and period of 4 s. Each of the films was obtained by initiating the treatment at a random starting motion phase, and marked with fiducials that were later used to register and add the films from successive fractions. The cumulated average following each fraction was subtracted from the 10-film average, which represented a previously validated approximation to the ensemble average accounting for all possibilities of starting motion phase, field loading time, and inter-beam setup time. **Results:** Marked differences in the shape of the isodose lines are observed between different fractions. A histogram distribution of the difference between the average 2D film dose distribution from 10 films and the cumulated average from successive fractions (1-9) showed progressive narrowing. The greatest change in the distribution occurred between fractions 1-3. The standard deviation of the distribution decreased to < 1 cGy after 6 fractions for motion in the M-L and S-I directions for step-and-shoot IMRT delivery and 7 fractions for dynamic arc delivery. **Conclusion:** Our results indicate that the interplay effects between the MLC and periodic tumor motion markedly diminish after 6-7 fractions for both step-and-shoot IMRT and dynamic arc delivery.

SU-FF-J-14

Determination of Displacement Binning Points for Four-Dimensional CT Image Acquisition

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Purpose: Present methods of generating four-dimensional (4D) computed tomography (CT) image data sets that bin either projections or reconstructed images based on the phase of the respiratory cycle might display artifacts caused by irregularities in the respiratory cycle. Binning based solely on displacement has the potential for resolving these artifacts but yields three-dimensional image data sets that are unevenly spaced in time, making the application of the 4D data set to treatment planning more difficult. We propose a method for displacement-based binning that sets the binning points at displacement points corresponding to approximately equally-spaced phases. Method and Materials: The present approach extracts the file used to monitor the patient's respiratory cycle and identifies the points on the respiratory cycle corresponding to true end-inspiration. The time intervals between each set of end inspiration points were divided into a specified number of phases (typically 10) equally spaced in time. The displacements corresponding to these phase points were averaged among the respiratory cycles included in the image acquisition, and the times in each respiratory cycle corresponding to the mean values were recorded and sent to the reconstruction program. A MATLAB program was written to generate these times and applied to a typical respiratory cycle. Results: When evenly-spaced displacements were used for displacement binning, the mean time intervals among the 10 phases varied by as much as a factor of 5. The present methodology reduced the variation in mean time intervals among phases to approximately 20%. Conclusion: f binning for acquisition of 4D CT image data sets is to be based on displacement of the respiratory trace, then, to ensure approximately equally-spaced time intervals, the displacement for a specific phase averaged over all respiratory cycles should be used. Conflict of Interest: Supported in part by a Sponsored Research Agreement with Philips Medical Systems, Inc.

SU-FF-J-15

Evaluation of Lung Tumor Dose Coverage in Free-Breathing Treatment Plans Using Respiration-Correlated CT

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Purpose: We quantify the effect of respiration on 3D conformal radiotherapy of lung tumors in terms of dosimetric end-points using respiration-correlated CT scans (RCCT). **Method and Materials:** Six patients received RCCT scans (GE Advantage4D CT). Repeat slices were obtained at each couch position and retrospectively sorted according to respiratory phase using an external respiratory monitor. We generated simulated free-breathing (FB) CT sets by assembling slices at different respiratory phases from the RCCT study. FB treatment plans similar to the clinical plan were created based on a 1.5 cm expansion of the gross tumor volume (GTV) in one patient and 1.0 cm in two other patients. Superposition-convolution dose calculations (ADAC/Pinnacle system) were used. We applied the FB plan to the RCCT data sets at various respiratory phases and evaluated dose coverage of the GTV and clinical target volume (CTV=GTV+6mm). **Results:** Initial results are presented for an extreme situation: the patient with the largest tumor motion (2.3 cm, inferior/superior direction) and the start phase of the simulated FB scan chosen to have the tumor at its most superior position. The D99% values are: 1) FB plan: GTV 5833 cGy, CTV 5706 cGy. 2) FB plan applied to end-inspiration: GTV 5828 cGy, CTV 5433 cGy. The GTV and CTV are only modestly underdosed at end-inspiration (tumor most inferior), in this worst case scenario (FB plan based on a tumor at a superior position). Dosimetric indices at end-expiration show less change. Preliminary studies on two other patients with smaller tumor excursions show similarly small dosimetric changes. **Conclusion:** Tumor coverage by free-breathing based plans with standard margins changes only slightly with breathing phase in an extreme case. This study examines only respiratory motion and not interfractional tumor motion or setup error which also affect tumor dose coverage.

SU-FF-J-16

Forward Planning to Account for Motion of Intrathoracic Targets Compared to the Standard Pre-Treatment Target Expansion Method Based On Internal Target Volume (ITV)

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Purpose: To compare geometric methods currently recommended by the ICRU versus forward dose calculation inclusive of motion for treatment planning of intrathoracic targets. **Method and Materials:** A deformable alignment tool (based on thin plate splines) is used to find the transformation from the exhale to the inhale CT volumes of the patient. Using this transformation and the exhale-defined gross target volume (GTV), inhale and mid-ventilation GTV volumes are constructed. These GTV volumes are then summed to make the internal target volume (ITV). A conformal plan is created to cover the ITV volume with 95% dose. To subsequently account for motion for this plan, dose is averaged over inhale, exhale and mid-ventilation phases by mapping the density grid of the treatment planning CT scan to these breathing phases, calculating the dose at each phase, and mapping the dose grid back to the reference CT.
In the forward planning method the plan is first conformed to the exhale GTV and then modified after each dose calculation (using the same method as above to account for motion) by adjusting the MLC leaves until the moving GTV is covered with 95% dose. **Results:** The impact of breathing motion on total dose to GTV and lungs was accounted for in both planning methods. The dose volume histograms (DVH) of the lungs showed a decrease of about 3% in the lung volume irradiated to higher doses for the forward planning infrastructure compared to the standard ITV planning. The forward planning reduced the total volume within the 95% isodose surface compared to the ITV plan. **Conclusion:** Forward planning that is robust to breathing movement is feasible. Minor decreases in lung dose compared to geometric methods warrant further investigation.

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SU-FF-J-17

Free Breathing Synchronized 4D Radiotherapy: Imaging, Treatment Planning, and Delivery

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Purpose: Develop four-dimensional (4D) radiotherapy to incorporate breathing motion in thorax, covering PTV adequately and reducing mean lung dose and V20 for lung. Analyze tumor and thoracic structures motion using the 4D-CT images. **Method and Materials:** Motion of tumor and thoracic structures of twenty lung cancer patients are studies, using a retrospective respiratory gating 4D-CT and external respiratory signal generator system. Breathing was synchronized with cine image acquisition, and retrospectively correlated based on respiratory phases. For 4D-delivery, MLCs were synchronized with respiratory motion and followed tumor with a safe margin selected based on reliability of patient breathing ranging from 100% largest static field to 0% the smallest dynamic field. **Results:** 4D-CT provides tumor motion in different phases of breathing cycle. The GTV/CTV delineated on helical CT without incorporating breathing motion underestimates GTV/CTV by 25-50% compare to the 4D-GTV/CTV delineated on 4D-CT image sets. The 4D radiotherapy reduces the mean lung dose by 16-32% (average 23%) and V20 reduction for ipsi lung by16-26% (average 21%) compare to the standard protocol. The volume changes of apex, mid and inferior regions of the lung during breathing are 11%, 24%, and 65%. The motion of tumors varies with the location. Tumors located in the apex move by 3-5mm, 2-4mm, and 2-3.5mm in superior/inferior, anterior/posterior, and right/left directions. Those located in mid lobe move by 6.5-9mm, 3.5-5mm, and 4-5mm, and those in lower lobe move by 7.5-12mm, 4-8mm, and 3.5-6.5mm. The superior/inferior motions of diaphragm, rib and carina range from 7-25mm, 2-7mm, and 3.5-13mm. On 4D delivery, we tested MLC synchronization with breathing motion on phantom. Lung volume coverage is minimized by a 20% safe margin. **Conclusion:** 4D-CT provides tumor motion in different phases of breathing cycle. 4D delivery synchronized with respiration-induced motion reduces mean lung dose and were synchronized with respiratory motion V20 for lung.

SU-FF-J-18

Guided Breathing for Aperture Maneuver with Controlled Breath (AMC)

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Purpose: The effectiveness of a breathing guide system by means of a visual signal with audio stimulus was evaluated for regulating patient's breathing. **Method and Materials:** A system for breathing guide by means of a visual signal with audio stimulus has been designed. It consists of a chromel–alumel thermocouple, which detects the temperature changes due to patient's breathing, and a mask, in which the thermocouple is installed. Patients were instructed to regulate their breathing by the guide of a visual signal with audio stimulus, as watching a display showing patients' current breathing pattern and visual signals (a guiding curve and limit lines) and listening audio stimulus (breathe in/out). Free breathing of five healthy volunteers was monitored. Then, they practiced regulating their breathing with our system and their guided breathing was recorded for an analysis. **Results:** With five-minute direction and thirty-minute practice, four patients out of five could regulate their breathing through this system without difficulty. While breathing was guided, the differences of displacement between patients' actual breathing and guiding curves were less than ± 0.3 cm and those of cycle between the two were less than 0.1 s. After practicing, patients could continue guided breathing for up to 70 s. **Conclusion:** This study reveals that a visual signal with audio stimulus is practical to guide patients' breathing to be regular. Therefore, when an aperture maneuver with controlled breath (AMC) technique, which adapts radiation fields continuously to a moving target, is applied with guided breathing, positional uncertainties of targets due to respiration can be reduced by 73 % compared to free breathing, so target margins can be reduced significantly.

SU-FF-J-19

How Much 4D Data Is Needed for Estimation of Dose Distribution Evaluation Metrics at the Time of Planning?

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Purpose: To investigate the number of intermediate states required to adequately approximate the cumulative dose to deforming/moving thoracic anatomy. **Method and Materials:** CT scans at exhale were registered to images and/or simulated data at inhale and 4 or more intermediate breathing states for several lung cancer patients using B-spline transformations. Doses to each state were computed using the DPM Monte-Carlo code and dose was accumulated for scoring on the exhale anatomy via the transformation matrices for each state and time weighting factors. Cumulative doses were estimated using increasing numbers of intermediate states and compared to simpler scenarios such as a "2-state" model which used only the exhale and inhale datasets (as these have the highest time weighting coefficients). Dose distributions for each modeled state as well as the cumulative doses were assessed using DVHs and several treatment evaluation metrics such as mean lung dose, NTCP and gEUD). **Results:** Although significant "point dose" differences can exist between each breathing state, the differences decrease when cumulative doses are considered, and can become less significant yet in terms of evaluation metrics depending upon clinical endpoint. For example, differences between a "2-state" and a "6-state" cumulative dose distribution are often within a few percent of each other and can have no significant clinical impact on treatment metrics for the lung itself as it is a large volume effect organ. However, the use of more intermediate states is sometimes required to properly estimate doses to other adjacent organs at risk such as the esophagus. **Conclusion:** This ongoing study suggests that for certain "clinical" endpoints it may only be necessary to properly give weight and accumulate the doses from a few well separated states (having the highest probability of occurrence) to achieve satisfactory predictions of the results of accumulating dose to the distorting anatomy.

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SU-FF-J-20

How to Explore Alternative 4D CT Image Binning
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Purpose: Most 4D CT datasets use some external respiratory monitor as a surrogate for respiratory-induced motion. The present work demonstrates the correlation between CT image acquisition times, times reported in the file of a respiratory monitor and how this information can be used to resort the 4D images. **Method and Materials:** 4D data sets of a motion phantom and of a patient were acquired using two scanners (GE Discovery ST, GEMS; MX8000-IDT, Philips Medical Systems), sorted and imported into a radiation treatment planning system (Pinnacle^3, Philips Medical Systems).

Displacements of a fiducial (RPM™, Varian Medical Systems) placed on the phantom were determined using the treatment planning system tools and recorded. These displacements were then correlated with displacements reported in the respiratory trace file.
Software has been developed to generate 4D datasets based on phase or displacement. In this example the mid-scan time (GE) or content time (Philips), as reported in the DICOM header in the CT image data sets, are used to correlate axial slices with fiducial displacement times. **Results:** The mid-scan time does not directly correlate with the time of fiducial displacement over repeated beam-on cycles. The mid-scan time does correlate within each individual beam-on cycle. Once the image times were correlated to those in the RPM files we extracted magnitude of fiducial displacement to effect displacement-based binning of CT images enabling the study of an alternative image-sorting scheme.
The content time requires a correlation of unequally spaced tags sent to the CT scanner. This technology is under development and requires more complexity in implementation. **Conclusion:** Alternative retrospective techniques of CT image binning can be pursued. The present system of phase-based binning demarked solely by the beginning cycle is effective, but can be improved by including more fiducial information. **Conflict of Interest:** MJF is supported by a Philips SRA.

SU-FF-J-21

Image Interpolation in 4D CT Using a BSpline Deformable Registration Model
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Purpose: To develop a method for deriving phase-binned 3D CT images through the interpolation of CT images at 2~3 known phase points.. **Method and Materials:** 4D-CT dataset for 3 patients were acquired. The deformation between inhale and exhale phases was quantified using a BSpline image registration model. During the registration calculation, the displacement coefficients defined on a lattice of nodes overlaid on the image were iteratively modified until optimal match was achieved. Images at an arbitrary phase were deduced by direct interpolation of the node coefficients. The interpolated images were compared with the actual 4D dataset and the results were evaluated by measuring the displacements of implanted fiducials in the two sets of images. Checkerboard and subtraction images between the interpolated and actual images were also computed. **Results:** The model was capable of describing the patient-specific anatomical deformation between the inhale and exhale phases and generating images at intermediate phases with a 3 mm accuracy. Subtraction images indicated only 0.1% of voxels having a difference >20 HU. The technique also mapped the organ contours at a known phase to other phases and provided an effective way for designing patient-specific margins in the presence of respiratory motion. Finally, the technique lead to a 90% reduction in the stored data because the 4D CT dataset of 25 million pixels can now be described by only a few thousand BSpline lattice points. **Conclusion:** Organ deformation during the breathing process can be modeled by using an interpolation of the deformation field with 3mm accuracy. To obtain images at any phase during a breathing cycle, it seems adequate to acquire only 2~3 sets of images at some distinct phases such as inhale and exhale points. The technique offers a practical solution for 4D-CT acquisition with greatly reduced radiation dose and binning artifacts.

SU-FF-J-22

Impact of Respiratory Motion On Dose Distributions and DVHs of Thoracic Structures – Evaluation Using 4DCT
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Purpose: Respiratory motion may have effect on dose distributions and DVHs of thoracic organs and tumors themselves. The purposes of this work are to determine (1) changes of doses and DVHs with respiration; (2) actual doses delivered to these structures upon completion of one treatment fraction. **Method and Materials:** Ten non-small-cell lung cancer cases were selected, all had free-breathing fast CT and 4DCT scans during normal breathing. These cases had acceptable breathing regularity and 4DCT image quality, sufficient motion of tumor and lung, and inclusion of entire lung. All cases were treated with 3D (8 cases) or IMRT (2 cases) techniques. Lung volumes were outlined on all respiratory phases consistently using a single CT-number threshold. Dose distributions were re-calculated for all phases, with DVHs obtained for each structure on all respiratory phases. For cases with significant changes of lung DVHs, deformable image registration was used to calculate total cumulative dose distribution combining all phases. **Results:** The overall dose distributions were rather insensitive to respiration for both 3D and IMRT beams except extreme cases with diaphragm moved in/out of beams. Thus, change of DVH for static structures (e.g. cord) was often insignificant. Large changes of lung DVHs were observed only for half of the cases, the degree of which was affected by tumor location and volume, and lung motion. Changes of PTV and heart DVHs were mainly caused by their translational movements. Use of free-breathing CT was inadequate to represent moving anatomies and could cause spurious results, whiles mid-inspiration CT provided the best estimate of average lung volume, mass, and dose distributions. **Conclusion:** Though dose distributions did not change significantly with breathing for photon treatments, variations of DVHs for thoracic structures were more complex and had to be assessed for individual patients and structures.

SU-FF-J-23

Improved Temporal Resolution by Respiratory Gated Segment Reconstruction: Towards Four-Dimensional (4D) Radiation Therapy for Heavy Ion Beams Using the 256-Detector-Row CT-Scanner
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Purpose: To perform more precise treatment planning for respiratory-moving tumors, we developed a respiratory gated segment reconstruction method (RS) based on the Feldkamp-Davis-Kress algorithm (FDK) which can achieve high temporal resolution and high signal-to-noise ratio. We compared full scan (FS-FDK) and RS-FDK with regard to the image quality and the obtained dose distributions for heavy ion treatment planning. **Method and Materials:** Data acquisition for RS-FDK relies on the assistance of the respiratory sensing system in a cine scan mode with a 256-detector row CT. We compared the image quality for RS-FDK to that for FS-FDK in phantom and animal studies. To evaluate the accuracy of the actual irradiation for the moving tumors, we compared the dose distributions of both algorithms in heavy ion treatment planning with the beam parameters of FS-FDK. **Results:** RS-FDK provided images without motion artifacts and visualized the edges of the liver and pulmonary vessels more clearly than FS-FDK. With regard to the iso-dose distributions, FS-FDK covered the target volume. RS-FDK, however, had an insufficient dose to the target and a considerable dose was deposited to the normal tissue around the target. **Conclusion:** RS-FDK has good capabilities for providing useful information to give accurately prescribed dose-to-target volume. It is possible to achieve more precise radiotherapy including 4D radiation therapy using the RS-FDK. Now we investigated 4D radiation therapy using the moving phantom, however we can summarized RS-FDK using lung cancer patients and 4D radiation therapy planning using carbon ion beam and its movie files by AAPM annual meeting.

SU-FF-J-24

Investigate On the Deconvolution Method to Compensate the Movement of the Object During PET Scanning

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Purpose: The deconvolution method to compensate the movement of the object during PET scanning was investigated. The motion artifact should be removed for exact staging of the patient. **Method and Materials:** The PET images for movable object with FDG using Biograph(Siemens, USA) were obtained. The FDG drugged small object with 1mm diameter and 5 cm long was installed at the end of the cam of the moving phantom. The profiles for Z-direction, movement direction, including the maximum intensity point, were extracted from the images. The 1-D movement of the phantom was calculated from the physical distance of the moving phantom. The iterative deconvolution method was implemented on the profile obtained from the moving phantom to compensate the movement of the object. **Results:** The profile from convolution between profile for stationary case and 1-dimensional movement of the scanning object was calculated. The maximum intensity of the stationary case (543,915 bq/ml) was 158% higher than the movable case(343,803 bq/ml). The calculated profile (319,685 Bq/ml) was well agreed with the movable one within 7%. **Conclusion:** Due to the movement during the PET scanning, the scanning signals are reduced and affect on the maximum SUV, derived from the maximum intensity in the interested region. The movement of the organ should be monitored by given solution such as RPM. The suggested iterative deconvolution method could be implemented on the most movable direction, and it could successfully remove at least 1-dimentional motion artifact.

SU-FF-J-25

Long Term Prediction of Respiratory Motion with Artificial Neural Network Based Adaptive Filtering Techniques

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Purpose: Respiratory motion prediction is a key component affecting the accuracy of respiration gated and tumor tracking radiotherapy. The aim of this research was to investigate ways to improve long term prediction of respiratory motion with artificial neural network based adaptive filtering techniques. **Method and Materials:** An artificial neural network (ANN) based adaptive linear filter was used to predict respiratory motion for 30 motion traces (4 mins duration each) obtained from 7 patients both with (audio-visual biofeedback) and without breathing training. Sequential training of the network was implemented using the Widrow-Hoff training algorithm after proper determination of the maximum stable learning rate. A signal history of 5000 msec was used for training. The errors from prediction were compared to those obtained with a simplistic adaptive linear filter from earlier work. The effect of breathing training on the predictive ability of the ANN based was also determined. **Results:** Magnitude of geometric errors from prediction for the ANN based adaptive linear filter ($\sim$ 2 mm - 1σ) were less than 50% of the magnitude of respiratory motion (5 mm - 1σ), especially for longer response times (> 600 msec). This represented a 40 % improvement in accuracy over a simple adaptive linear filter without any learning features. Breathing training with audio-visual biofeedback resulted in a slight reduction in errors from prediction. **Conclusion:** Artificial neural networks offer unique features that can help improve the adaptive capabilities of predictive filters. Further improvements in prediction of respiratory motion are possible with further developments using such a framework.

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SU-FF-J-26

Multistage Treatment Planning Optimization for Managing Organ Motion in Radiotherapy Planning

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Purpose: The management of breathing-registered IMRT treatment planning is explored by incorporating the motion pattern of breathing directly into the treatment planning process. The movement of the voxels from one CT timeframe to another is ``tracked" and modeled. A timestamp for each voxel specifies its position throughout the breathing cycle. The treatment models incorporate planning constraints throughout multiple time periods. Robustness of the algorithm, plan quality, and potential clinical significance are evaluated. **Method and Materials:** 4D-CT scans of lung 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)Multi-stage optimization and planning, where movements of voxels from one CT-timeframe to another are "tracked" and modeled, and planning constraints are incorporated throughout the multiple-phase period. Sophisticated computational optimization techniques are used to solve these models. **Results:** Applied to a lung case, the static-PTV plan results in unacceptable PTV-underdose. Multistage-plans offer as good coverage as the ITV-plans, comparable minimum PTV dose while simultaneously reducing the mean-dose to left lung normal tissue(20%), heart(20%), and esophagus. **Conclusion:** Multistage 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 are 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. Further investigation of ITV will be conducted to understand if improved plan quality can be achieved via improved construction of this structure. Clinical studies are needed to validate the importance of our approach to treatment outcome.

SU-FF-J-27

Novel 4D CT Scanning Protocol Using a Helical Single-Slice CT Scanner

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Purpose: In radiotherapy, respiratory motion poses a significant challenge during tumors imaging, treatment planning and radiation delivery. A method to alleviate respiratory motion problems is to use 4D radiotherapy. We propose novel 4D CT scanning protocol using a helical single-slice CT scanner (SSCT). **Method and Materials:** In our protocol, patient's torso is scanned three times using the helical mode of a SSCT scanner. CT slices are acquired simultaneously with real-time tracking of a marker placed on patient's torso. At the end of the three scans, CT data is binned into different respiratory phases according to the externally recorded respiratory signal and the volume of interest is reconstructed for several respiratory phases. **Results:** The protocol was tested on an anthropomorphic phantom to which a realistic respiratory motion was induced by placing it on an inflatable mattress driven by an air pump controlled by a pulsing power supply. 4D CT images were compared with images obtained after a conventional scan of the static phantom and with the conventional scan of the "breathing" phantom. 4D CT images show a net improvement with respect to conventional CT images. The ANIMAL deformable registration algorithm was used to calculate a 3D vector mesh which maps volumes at any given phase to the exhale volume. This vector map and the external breathing signal are used to reconstruct the anatomy at any breathing phase. **Conclusion:** Our scanning protocol uses the helical scan mode so it is faster than the axial/cine scanning protocols. The gap between CT slices available for each breathing scan is alleviated by taking three successive scans but the use of low tube current keeps the dose to the patient to an acceptable level. Our protocol is easy to implement in any clinic where a single-slice CT scanner and a real-time motion tracking system are available.

SU-FF-J-28

Preliminary Study to Use Non-Rigid Registration for Target Tracking and Dynamic Treatment Planning

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Purpose: to prove the feasibility of non-rigid registration of CT scans taken from a temporal series in thoracic and abdominal radiosurgery. **Method and Materials:** for 5 patients 2 CT scans were acquired in end-exhale and

end-inhale condition. The radiation oncologist identified the lesion in both examinations. We chose a voxel-based non-rigid registration using B-Splines Free Form Deformation (FFD) with a local rigidity constraint. We created a mask to include only the target and applied the calculated deformation to it to evaluate position and shape of the lesion. We estimated the mass centres of target displacement between two moments of the breathing cycle and evaluated the variation of the volumes. **Results:** from the analysis of the mass centre movements it follows that the maximum displacement was in inferior/superior direction. The most relevant case was a lesion placed close to the diaphragm that showed large movements in anterior/posterior direction and also in the inferior/superior direction (18.6 mm). Volume variations were equal to 15% in two cases, 1.5% and 6 % in other two. Only a small lung lesion showed a big increase, due to the fact that this target contained a margin of nearby tissue affected by large deformation during the breathing cycle. The targets obtained by non-rigid registration were similar to those identified by the radiation oncologist. **Conclusion:** this study shows the possibility to apply non-rigid registration for a more accurate radiosurgery treatment. In particular, among the applications of this study it should be possible to follow the target movements/deformations and calculate the dose distribution by taking into account the changes of tissues during all the instants of breathing, providing both the complete target tracking and the dynamic treatment planning.

SU-FF-J-29

Quantification of 4DCT Determined Lung Tumor Motion Based On Image Registration

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Purpose: To examine the feasibility of rigid-body image registration for tracking lung tumors and to determine motion characteristics of these tumors. **Method and Materials:** Respiratory correlated 4DCT scans for 55 GTVs in 50 patients were obtained using a commercial 4DCT (Discovery ST, GE Healthcare, Waukesha, WI) which generates 10 CT datasets sorted by respiratory phase. Tumor displacements were measured with an image registration software package which uses a cross-correlation algorithm to track tumors across the 4DCT datasets, assuming rigid motion. The reference template of each tumor was determined from the physician-contoured GTV on the patient's expiratory scan. The automatic registration was validated by visually comparing the shifted GTV contours to the image of the tumor across the 4DCT datasets. The diaphragm motion was also extracted from the 4DCT images. **Results:** In 96% (53) of the cases, automatic registration of the tumors agreed with the observed tumor motion. We found that 53% (29) of tumors moved more than 0.5 cm, among which 13% (7) moved more than 1 cm with the largest observed motion being 1.7 cm. For tumor displacement along each principal axis, we found 47% (26) of tumors moved more than 0.5 cm in the SI direction. In contrast less than 2% of the tumors moved more than 0.5 cm in the lateral and AP directions. We were able to correlate tumor motion with diaphragm motion only for tumors less than 150 cc in the lateral 45% of the lung (correlation coefficient=0.83, p=0.004). **Conclusion:** Image based rigid registration is appropriate for tracking tumors moving with respiration. Motion quantification is critical in lung cancer as, per this study, half of all tumors move significantly (>0.5 cm) and this motion is non-isotropic. A strong correlation between tumor size, location and motion was only found for a small fraction (<25%) of tumors.

SU-FF-J-30

Quantification of Normal Organ Motion Due to the Respiratory and Cardiac Cycles

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Purpose: To quantify the degree of normal organ motion due to the respiratory and cardiac cycles. Better definition of such motion may be useful in defining field margins and in assessing the utility of gating technologies. **Method and Materials:** Four healthy volunteers were serially scanned in the supine position with a GE 1.5T MRI scanner. T1-weighted sagittal and coronal localization scans were first performed to define the regions to be studied. Axial images through the heart, liver and pancreas were continuously scanned with fast cine MRI scans at three different gating settings: a). without either respiratory or cardiac gating, b). with respiratory gating but without cardiac gating, and c). with both respiratory and cardiac gating. The motions of heart, liver and pancreas were calculated at the organ edges with the maximum motions along the direction that is perpendicular to the edge. **Results:** For the scans without either respiratory or cardiac gating, the detected organ motions on the axial slices were 1.4 cm for heart, 1.1 cm for liver, and 1.0 cm for pancreas. For the scans with respiratory gating but without cardiac gating, the motions were 0.7 cm for heart, 0.5 cm for liver, and 0.4 cm for pancreas. For the scans with both respiratory and cardiac gating, all the motions were <0.2 cm. The AVI movie files were also created and showed significant differences in organ motions for three different gating settings. **Conclusion:** With respiratory gating only, significant organ motion is still present in heart, liver and pancreas. In some clinical settings, the application of both cardiac and respiratory gating may be therapeutically advantageous. Additional study is warranted to better understand this issue. **Conflict of Interest:** Authors received grant support from Varian Medical Systems.

SU-FF-J-31

The Clinical Implications of Dynamic Therapies

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Purpose: To quantify the effects of respiratory motion on breast treatments and to quantify the improvements in dose homogeneity when implementing gating therapy. **Method and Materials:** A breast phantom was constructed based on the average contours of 6 patients undergoing treatment of breast cancer. Dose to three axial planes was measured: superior, middle, and inferior. A respiratory simulator was designed to mimic breathing motion to a first order approximation. Three treatment types were compared: physical wedge compensators (PWs), enhanced dynamic wedges (EDWs), and step-and-shoot IMRT (ssIMRT). Four wedge angles (15º, 30º, 45º, and 60º) and three velocities of the phantom (v = 1.38 cm/s, v = 1.01 cm/s, and v = 0.50 cm/s) were studied. Dosimetry for each dynamic case was also analyzed when the Real-Time Position Management Gating System was implemented. Film was used as a dosimeter, dose area histograms (DAHs) were calculated for a breast and lung planning target area (PTA), and Normalized Agreement Test (NAT) Indexes were calculated in reference to the static case. **Results:** In general, gating therapy improved dose to the breast PTA by up to 14% and reduced dose to the lung PTA by up to 24%. Dose homogeneity was dependent on respiratory rate and phase shift. Deviations from the static case were highest if the collimator speed was of the same magnitude as the speed of the phantom. With ssIMRT, gating the beam may compromise dose coverage of the breast PTA if the timing interval of the gate is too large. Gating the beam decreased NAT Indexes by 9 for PWs, by 16 for EDWs, and by 6 for ssIMRT. **Conclusion:** Introducing gating therapy showed a significant improvement in dose homogeneity to the breast and lowered dose to the lung PTAs for all three treatment types.

SU-FF-J-32

Use of Internal Body-Area as a Metric for Retrospective 4D CT Gating

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Purpose: Current 4D CT acquisition techniques require the use of an external breathing metric, which adds time, cost and complexity to the procedure. If the use of the metric is not required after the imaging session, an internal metric may be adequate. The purpose of this study was to evaluate the use of the cross-sectional body area as an imaging-based internal metric for breathing motion using CT images acquired during free breathing. **Method and Materials:** A 16-slice CT scanner (Philips Brilliance) was operated in ciné mode to acquire 25 scans consecutively at each couch position while patients underwent simultaneous quantitative spirometry. The cross-sectional body area was computed by automated image segmentation. The body areas for the 16 slices within each 2.4 cm-thick couch position were summed and compared to the corresponding tidal volume. The correlation between tidal volume and body area were examined to evaluate the quality of body area as a metric. **Results:** Three patients were analyzed. The body area consistently show a high correlation with the tidal volume in the abdomen (correlation coefficients > 0.8, and residual error < 10% of the total tidal volume). In the upper lung region,

the correlation coefficients varied in a range of 0.2 to 0.99, and the residual errors were 5% to 30%. For each patient there was a transition region near the mid sternum where the correlation degraded dramatically. **Conclusion:** For imaging of the upper abdomen, the body area appears to be a good breathing metric for generating 4D imaging studies. One method for improving this process may be to overlap successive couch positions by one slice location, thereby providing a CT slice with overlapping body-area measurements.

SU-FF-J-33

Using CT Cine Data as An Alternative Method for Respiratory Phase Analysis and a Potential Method for Tumor Motion Study

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Purpose: To demonstrate the use of cine images from 4D-CT imaging as an alternative method to obtain respiratory signal for sorting of the 4D-CT data, and as a tool to understand the relationship between the externally measured respiratory signal and the internal tumor motion. **Method and Materials:** Six lung patients were scanned in the tumor region with coverage of approximately 8 cm. The respiratory trace for each patient was clinically acquired using the RPM system placing the RPM block near the diaphragm. The cine images were used as an alternative method to obtain respiratory signal by measuring CT density variation versus time in a region of interest chosen at the boundary of tissues with high CT density contrast. We also placed a region of interest to measure the CT number changes as a way to describe the tumor motion in either superior-inferior or anterior-posterior direction. We compared the respiratory signal from RPM and the respiratory signal from cine images and correlated the two respiratory signals with the internal tumor motion (also from cine images). **Results:** Images can be sorted to become 4D-CT data using the respiratory signal measured from cine images. When compared to the RPM signal, the respiratory traces measured using the cine images, showed phase differences ranging from 2% to 25%. Tumor motions observed using the cine data for three patients showed 50% phase difference in S-I direction and 0% and 25% phase differences in A-P direction from the respiratory signal of the RPM block. **Conclusion:** We have demonstrated that cine data can be used as an alternative way of acquiring respiratory waveform for 4DCT images registration. The tumor motion can also be studied using the cine data. The 4D-CT data can also help us understand the relationship between internal tumor motion and the externally measured respiratory signal.

SU-FF-J-34

Video-Surface-Guided Respiratory Motion Correction for 3D Static CT Images

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Purpose: Three-dimensional (3D) static CT images of structures in the thorax and abdomen constantly suffer from artifacts caused by periodic respiratory motion. This study presents a novel method to correct respiratory motion for 3D CT images by correlating CT images with dynamic body surface models in which physiologic motion of body surface is recorded with the aid of a 3D video imaging system. **Method and Materials:** We introduce a new dynamic CT imaging technique that utilizes a commercially available high-speed 3D camera system to gather magnitude and frequency information of respiration cycle by acquiring the motion of body surface. A dynamic body surface model is built to record 3D surface geometry and texture information at different phases of respiration cycle. Retrospective gating technique is then adopted to correlate or register CT images with the dynamic body surface model. Multiple skin markers shown on CT and video surface images are used for verification of the dynamic model. **Results:** In this study, motion artifacts were remarkable reduced and accurate 4D CT datasets were generated for the further use by planning systems. **Conclusion:** Quantifying internal anatomy motion as a function of respiration cycle is important in conformal radiotherapy, especially for lung and breast tumors. Compared to conventional 3D CT, four-dimensional CT (4D CT) techniques present overwhelming advantage on imaging objects undergoing periodic motion. The feasibility of 4D CT techniques based on a 3D video imaging system has been demonstrated in this work. Correlating these images with the dynamic body surface models reduced respiratory motion artifacts for 3D CT images. **Conflict of Interest:** Partially supported by the camera company.

SU-FF-J-35

A Comparison Between BAT and Tomotherapy MVCT On Inter-Fractional Prostate Localization

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Purpose: To compare the clinical utilities of two image-guided target localization systems in fractionated external beam radiotherapy: BAT™ ultra-sound system and TomoTherapy™ mega-voltage computed tomography (MVCT) system **Method and Materials:** Daily prostate setup verification data is obtained for 40 patients undergoing prostate external beam radiotherapy at University of California – Davis cancer center, using the ultra-sound based target localization system (BAT™, North American Scientific, Chatsworth, CA). This set of data contains translation (superior-inferior, lateral and anterior-posterior) setup errors. At the University of Arkansas for Medical Sciences, 12 prostate patients undergoing helical tomotherapy (TomoTherapy Inc., Madison, WI) are helped with onboard MVCT to guide inter-fractional prostate setups. The obtained MVCT data contain both translation and rotational (pitch, yaw and roll) setup errors. Statistics analysis using Microsoft Excel is done for both data sets. **Results:** BAT™ and MVCT reported similar magnitude of inter-fractional prostate setup errors in this study. This result agrees with another direct daily CT and BAT™ comparison study reported by Lattanzi *et al.* (1999). However, our data show a larger range of distribution due to different groups of patients at different institutions being used in this study (more detailed data analysis result and discussion is reported with the attached supporting document). **Conclusion:** Both BAT™ and Tomotherapy MVCT can be applied to image-guided inter-fractional prostate setup procedures. These techniques are principally more accurate than conventional skin tattoo based setups in clinical practice.

SU-FF-J-36

Clinical Implementation of An Eye Fixing and Monitoring System with Head Mount Display

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Purpose: A system to non-invasively fix and monitor eye by a head mounted display (HMD) with a CCD camera for stereotactic radiotherapy (SRS) of uveal melanoma has been developed and implemented clinically. **Method and Materials:** The eye fixing and monitoring system consists of a HMD showing patient a screen for fixing eyeball, a CCD camera monitoring patient's eyeball, and an immobilization mask. At first, patient's head was immobilized with a mask. Then, patient was instructed to wear HMD, to which CCD camera was attached, on the mask and see the given reference point on its screen. While patient stared at the given point in order to fix eyeball, the camera monitored its motion. Four volunteers and one patient of uveal melanoma for SRS came into this study. For the volunteers, setup errors and the motion of eyeball were analyzed. For the patient, CT scans were performed, with patient's wearing HMD and fixing the eye to the given point. To treat patient under the same condition, daily CT scans were also performed before every treatment and the motion of lens was compared to the planning CT. **Results:** Setup errors for four volunteers were within 1 mm and the motion of eyeball was fixed within the clinically acceptable ranges. For the patient with uveal melanoma, the motion of lens was fixed within 2 mm from daily CT scans. **Conclusion:** An eye fixing and monitoring system allowed immobilizing patient as well as monitoring eyeball and was successfully implemented in the treatment of uveal melanoma for SRS.

SU-FF-J-37

Generic Motion Kernels for Treatment Planning Incorporating Interfraction Motion

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Purpose: To generate motion kernels for treatment planning incorporating interfraction motion. **Method and Materials:** Patients undergo MVCT guided tomotherapy treatments were enrolled in this study. Patients were set up using skin markers and lasers; daily MVCT images were acquired; the MVCT images were then registered to treatment planning KCVT by automatic and/or manual rigid body image registration. Patient shift was recorded and analyzed. Up to date, data from seven lung cancer and nine prostate cancer patients were acquired.
Patient shifts were grouped according to the diseases and plotted in histogram. Generic motion kernels were derived by fitting distribution profiles into functions. For verification purpose, the daily shifts for each individual patient were also analyzed and compared to the generic ones. **Results:** The daily patient shifts are principally normal distributions. Generic motion kernels were obtained for lung patients and prostate patients by fitting the distributions into Gaussian functions. The standard deviations in x, y and z directions were 0.4, 0.62 and 0.62 cm for the lung and 0.32, 0.74 and 0.63 cm for the prostate. The standard deviations of individual patients range from 0.21 to 0.33 cm in lateral direction, 0.19 to 0.57 cm in longitudinal direction and 0.21 to 1.47 in vertical direction. The mean values significantly deviated from zero. **Conclusion:** Generic interfraction motion kernels obtained from large group of patients can be used for inverse or forward treatment planning to account for interfraction motion.

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SU-FF-J-38

High Precision Mask Based Patient Positioning System

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Purpose: Island mask with infrared (IR) markers is designed for camera based high precision patient positioning system. This system is suitable to monitor head and neck IMRT, edentulous and pediatric patents' inter-fractional and intra-fractional movement where current industrial standard bite plate system is not able to apply on the above described patients. **Method and Materials:** Thermoplastic and Styrofoam are used to make an island mask with the following procedures: First, cut the thermoplastic into a predefined template shape; Styrofoam cut into wedge shape with 1 inch in height and has area at least $9\times9cm^2$ for supporting five IR markers. Second, put the upper portion of template between philtrum and forehead and wrap the lower portion of template around with the Styrofoam wedge in it. Third, make two ear straps to fix the mask through the ears. Exactrac (BrainLAB Inc.) IR camera system is used for this study. The positioning reproducibility of mask system is examined against the bite plate system. The shrinkage of mask and optimal position of placing IR markers are also assessed. **Results:** The shrinkage of mask is within 1 mm and become stable 30 minutes after the mask has been cooled down. The positioning reproducibility of individual marker is worse for the marker located near the peripheral of the mask, and also symmetric pattern of markers is not allowed due to the "ambiguity" of the IR camera system. Therefore, the pattern of markers is an irregular shape and markers are located at the flat platform near the center of the mask. The overall positioning reproducibility of mask is within 1.4mm on five non-patient subjects. **Conclusion:** Our study shows that this mask based patient positioning system is an alternative of patient who can not use bite plate system but needs inter-fractional and intra-fractional movement monitoring.

SU-FF-J-39

Image Guided Radiation Therapy: Investigation of Interfraction Setup and External Contour Variation for Prostate IMRT Using CT and MRI

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Purpose: The interfraction setup and external contour variation during a treatment course may directly impact the accuracy of dose delivery. The purpose of this study is to investigate these effects for prostate IMRT using CT and MR images. **Method and Materials:** Eleven prostate patients were included in the MRI studies. Each patient underwent MRI scan once a week prior to treatment resulting in 4-6 MRI scans. Paired MRI scans were obtained in the treatment position in both an alpha cradle and a stereotactic body frame. External contour variations were quantified from the isocentric MRI slices. The immobilization and setup uncertainty between the alpha cradle and the body frame were evaluated. Eighteen prostate patients were included in the CT studies using a CT-on-rails system twice a week. Paired scans were generated before and after the treatment. BB/isocenter positions and external contours were quantified on both CT and MR images. **Results:** The isocenter and target localization accuracy was ensured to within 3 mm with in-room CT imaging. The maximum interfractional differences in external contours ranged 0.5 - 2.2 cm over the whole treatment course for patients with lateral dimensions of 34 – 43 cm. The patient lateral sizes fluctuated up to 5% compared with the initial simulation CT. In general, contour variations increased with the patient size. The maximum contour difference measured with MRI in an alpha cradle was 4.3 ± 2.8mm (ranged 0-9.5mm) while with a body frame it was 8.1 ± 4.1mm (ranged 3.3 -16.2 mm) for patient sizes between 35 and 39.5cm. **Conclusion:** Image guidance improves isocenter and target localization accuracy for prostate IMRT. Large interfraction setup and external contour variations (2cm) may occur for large patients due to obesity, which may alter daily dosing by 2-4%. An alpha cradle introduces less external contour variation than a body frame.

SU-FF-J-40

Independent Measurement of CyberKnife Synchrony Accuracy Using Optical Tracking

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Purpose: Synchrony provides respiratory motion compensation for CyberKnife by monitoring skin motion and dynamically steering the beam to follow the moving tumor. This study is designed to measure the accuracy and precision of the beam steering by recording the motions of both the linac and a ball-cube target using an independent optical tracker. **Method and Materials:** The target is a ball-cube phantom, which was CT scanned and planned for a 3000 cGy at 100% isodose line treatment using dynamic SRS (Synchrony). Respiratory motion was generated using a computer-controlled 3D motion simulator. We simulated regular respiratory motion as three sinusoids with the following extents: 10 mm SI, 10 mm AP, and 5 mm LR. The respiratory period was 5 seconds. All three axes were in phase. We used the Optotrak Certus (Northern Digital, Waterloo, Canada) optical tracking system for measurements in this study. Active LEDs were attached to the linac and the motion simulator to provide constant measurement of their position. Measurements were recorded at 30 Hz. We measured the tracking accuracy by computing the distance between the linac and the target. When Synchrony is active, the linac should follow the motion of the target exactly, so this distance should remain constant. We used the standard deviation of the linac-to-target distance during each beam as a measure of the beam steering accuracy. **Results:** We were able to track 61 of the 98 beams used during treatment. Other beams were not trackable because the linac or robot blocked the view of the Optotrak. Based on these beams, the standard deviation of the linac-to-target distance was 0.82 +/- 0.27 mm. **Conclusion:** These measurements provide independent, high-precision measurement of the tracking accuracy of CyberKnife with Synchrony. They demonstrate the system's capabilities for respiratory motion compensation.

SU-FF-J-41

Monitoring of Intra-Fractional Patient Motion During High-Dose Extra-Cranial Paraspinal Radiosurgery

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Purpose: Patients undergoing high dose single fraction radiotherapy to para-spinal sites are setup in a non-invasive immobilization cradle. We study the use of a portable infra-red tracking system for monitoring intra-fractional patient motion. **Method and Materials:** Infrared reflectors are affixed on the immobilization cradle, and taped to specific points of the patient to monitor positions or track breathing. A commercial stereoscopic infrared camera continuously tracks all the reflectors. Custom software determines the positions of the patient reflectors relative to the coordinate system of the cradle to assess motion during the treatment. Prior to

treatment, the system runs in a learning mode for several breathing cycles to acquire baseline data for comparison with reflector positions detected during the treatment. The displacement of each reflector from its baseline is displayed on a computer screen for continuous monitoring. For the purpose of this study, a 3D patient shift between the beginning and end of treatment was determined by averaging the individual 3D displacements of reflectors attached to skin overlying bone (sternum, hips). **Results:** A QA procedure of system accuracy determined that 0.5mm shifts of individual reflectors can be detected. Patient tracking data are consistent with observed patient shifts seen with portal imaging. For the patients studied, each component of the shift seen by the system was within 1mm of the corresponding shift of the bony anatomy in the vicinity of the target seen between pre and post treatment portal imaging. **Conclusion:** The system allows the detection of shifts of 2 mm or more as they occur and is therefore clinically useful. This may occur if a patient adjusts his position, for example. The ability to detect smaller shifts that occur slowly is under study. The system provides a real-time measure of patient safety during high dose treatment and is in clinical use.

SU-FF-J-42

Phase Lag Measurements of Abdominal Organs Relative to An External Marker Block Using Retrospective 4D CT Imaging

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Purpose: The purpose of this study is to quantify the phase lag of superior-inferior abdominal organ motion relative to an external marker block used to monitor respiratory motion. The diaphragm, liver, spleen, and kidneys were studied. **Method and Materials:** A 4DCT (GE Medical System, Waukesha, Wisconsin) scan correlated with respiratory motion using the Real-Time Position Management (RPM) Respiratory Gating System (Varian Medical Systems, Palo Alto, CA) was used to acquire scans of 10 patients. Up to 10 images at each slice location within one breathing cycle were acquired and sorted into respiratory phases evenly distributed in time. The superior and inferior edge of each organ was identified, and the average of these positions was used as the S-I position of the organ. The anterior edge of the external marker block was also recorded. These positions were identified for all respiratory phases. The data was then fit with a cosine squared function. The argument of the function was the observed respiratory phase plus a starting phase. The starting phase was then adjusted until the value generating the least square deviation among all measurements of the particular organ, diaphragm, or marker block for all phases was found. The difference of starting phase minus that of the marker block is then recorded as the phase lag relative to the marker block. **Results:** No phase lag is greater than 36° which is the minimum difference between successive phase for a respiratory cycle divided into 10 phases. **Conclusion:** The external marker block used to monitor respiration is observed to be in phase the motion of the abdominal organs and diaphragm within the measurement accuracy. **Conflict of Interest:** Software provided by GE Medical Systems

SU-FF-J-43

Technical Evaluation of Respiration Monitoring Devices and Breathing Training Techniques

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Purpose: To compare external respiration monitoring devices and breathing training techniques for use in gated imaging and radiotherapy. **Method and Materials:** Respiration was monitored on four humans with three devices: a spirometer, a pressure gauge inside an adjustable belt, and an infrared marker tracking system. Monitoring was performed under free breathing, with audible instruction, with visual instruction, and with both audible and visual instruction. Each test was executed for two minutes. Belt placement was tested on both the chest and abdomen, while marker placement was on the abdomen alone. Period and amplitude variability was analyzed on all traces to determine optimal belt placement and instruction technique. Individual cycle periods were compared between the three devices to test their correlation. **Results:** Abdominal belt placement was optimal in all aspects. The uncertainty in periodicity with all devices was 4.6%, 15.3%, 18.6%, and 16.7% for free breathing, visual instruction, audible instruction, and both instruction techniques, respectively. The most consistent relative amplitudes were found using both instruction techniques. Significant drift in amplitude was observed under free breathing conditions. Comparison of individual cycle periods showed that the pressure gauge and infrared marker systems agreed on average within 10 ms, while the spirometer data differed from the others by 60 ms on average. **Conclusion:** If using a pressure gauge system, the belt should be placed around the patient's abdomen. The most consistent periodicity results from free breathing, while the most consistent amplitude results from visual and audible instruction. The differences in period measurement between the devices can be attributed to the differences in sampling interval, while the consistently larger difference found with the spirometric data most likely is due to the calculation of volume from measured flow.

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SU-FF-J-44

PET/CT Imaging for 3D In-Vivo Treatment Verification in Proton Therapy - a Feasibility Study

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Purpose: to investigate the clinical feasibility of off-line PET/CT for in-vivo treatment verification of proton therapy. **Method and Materials:** Two PMMA blocks and one inhomogeneous phantom consisting of PMMA and muscle and bone equivalent slabs were irradiated with one or two orthogonal SOBP proton fields (8×8 cm^2 aperture, 10 cm modulation and 15 or 16 cm range in water). The targets were imaged using a PET/CT (CPS/Siemens Biograph Sensation 16) scanner within 20 min after irradiation. At first, a high dose of 8 Gy was delivered and 1 h listmode acquisition was performed to investigate image quality based on counting statistics in variable time framesets. In the other studies a maximum dose of 2 Gy was applied and acquisition was limited to 20 min to mimic realistic therapeutic cases. The amount and spatial distribution of measured activity was compared to calculations based on the FLUKA Monte Carlo code and experimental cross-sections. Proton range was extracted from the analysis up to the second derivative of the activity distal edge. Isotopes were identified from decay time analysis. **Results:** The shape of the irradiated field and the range-correlated activity distal edge could be imaged with sufficient accuracy after therapeutic doses, despite the delay between irradiation and scan. In PMMA, maximum ^{11}C activation (0.9±0.1 kBq/Gy/ml after 1.0–1.6 Gy/min irradiation) and distal edge position agree within 2% and 1% with calculations, respectively. Besides ^{11}C, minor amounts of ^{15}O and ^{13}N were identified at the beginning of acquisition. **Conclusion:** This feasibility study indicates the potential of off-line PET/CT for range and field position verification in proton therapy. In addition to PET alone, PET/CT provides information on possible anatomical changes during fractionated radiotherapy. Clinical patient studies addressing the accuracy and possible limitations due to perfusion are planned. If available, preliminary clinical results will be presented.

SU-FF-J-45

A Fluence Deformation Based Technique for Portal Image-Guided Adaptive Head-And-Neck IMRT

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Purpose: Recent studies have shown significant inter-fraction patient anatomy changes over the courses of fractionated head-and-neck IMRT. Current IMRT planning uses a fixed 3D-margin around CTV to account for these changes and patient setup errors, which results in high-dose to the normal tissues in the margin and may limit the treatment. We are developing an online portal image-guided adaptive technique aimed at reducing the margin by adapting the photon fluence to these inter-fraction changes. **Method and Materials:** This technique uses portal images taken at each treatment gantry angle and compares them with the corresponding DRRs from the planning CT. First, a deformable registration is performed to determine a 2D transformation between the two images. This transformation is then applied to the originally optimized fluence to obtain

a deformed fluence map that adapts to the detected changes. Finally, MLC sequences and deliverable fluences are re-calculated for adaptive dose delivery. Initial development used planning studies where rigid anatomy changes were simulated in the plan by shifting the isocenter, gantry angle and couch angle. Simulated DRRs were used as approximate representations of online portal images. Dose distributions and DVHs were calculated and compared to those from the originally optimized IMRT plan. **Results:** Preliminary results of applying this technique to head-and-neck patient data: 1) Deformed fluences calculated from transformations obtained by registering the portal images to the DRRs; 2) Comparisons of the resulting dose distribution of the adaptive technique to the one from the originally optimized plan. **Conclusion:** Preliminary results suggest that this fluence deformation based adaptive technique can geometrically account for simple rigid anatomic variations including 2D shifts-rotations. Evaluation of the full extent of dosimetric outcome from applying this technique and implementation of deformable registration algorithms for adapting to more complex anatomic changes, such as 3D deformation and volume change, are in progress.

SU-FF-J-46

A Probabilistic Method for Online Treatment Plan Modification

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Purpose: To develop an IMRT treatment planning method that accounts for increased knowledge of tumor and normal tissue location gained from inter- or intra-fractional imaging. **Method and Materials:** Knowledge of tumor location in each fraction or sub-fraction is represented by a probability density function (pdf), $p(n,n',t)$, that describes the probability that a voxel at index n in the planning image will be located at voxel n' at a later time t. The pdf is changing as the new information becomes available. A set of beam profiles for each fraction or sub-fraction is then obtained by minimizing the quadratic objective function by accounting for probabilistic nature of the beamlet dose distribution: $\langle d \rangle_{n,t} = \sum_{n'} d_{n'} p(n,n',t)$. in each fraction. This optimization problem is set with the intention that the beamlets that have the highest risk of missing the tumor will not be delivered until adequate knowledge of tumor location becomes available. We apply this method to a case of a disk-shaped tumor inside a disk-shaped phantom with a tomotherapy beam geometry. **Results:** The method proved to deliver more conservative dose distributions at the beginning of treatment than at the end for both inter- and intra-fractional cases. For early fractions and sub-fractions, low-risk doses were delivered to regions where the probability was high that the tumor would be present during the treatment. As knowledge of tumor location improved, the remaining dose at the periphery of the tumor was filled-in. **Conclusion:** We showed that incorporating increased knowledge about tumor and normal tissue location, obtained by repeatitive on-line imaging leads to superior treatment plans.

SU-FF-J-47

A Proposal of Respiratory Phantom Driven by Double-Motor

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Respiratory motion phantom has been widely used in the current study of gated radiotherapy. Most of the phantoms are driven by a single motor, which can only simulate one-dimensional sinusoidal motion. However, many studies had shown the normal breathing pattern is asymmetric between the inhale phase and the exhale phase. Fourier transform analysis shows that a double harmonic model, including the first and second harmonics, could give a good reproduction of the normal breath pattern. Based on this fact, we propose the design of a double-motor driven phantom, which can produce a periodic motion with asymmetric pattern. In this design, the phantom is driven by the first motor. This motor is fixed on a sliding platform, which is further driven by a secondary motor. The frequency for each motor can be adjusted with the input voltage, and should be set exactly according to the first and second harmonics, respectively. Amplitude of each sinusoidal component can be adjusted by changing the location of the arm on the wheel. Based on the Fourier analysis of real volunteer's data, the ratio of their amplitudes should be around 3:1 to 5:1, but could also patient adapted. This design can be valuable in phantom studies where a symmetric sinusoidal motion is not sufficient. Although a programmable phantom shows promising of an ideal solution, this design is easier to be implemented and also cost effective.

SU-FF-J-48

A Slice-By-Slice CT-Guided Adaptive Radiation Therapy Technique for Twisting Targets

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Purpose: To investigate a CT-guided adaptive radiation therapy technique capable of correcting for complex shape changes, including twisting around the longitudinal axis, such as found when treating head and neck patients with a head rotation. **Method and Materials:** For co-planar beams, the dose in an axial plane is primarily associated with the positions of a single MLC pair. We start with a primary plan, and automatically generate several secondary plans with gantry angles offset by regular increments. MLC sequences for each plan are calculated keeping MUs and number of segments constant for a given beam (fluences are different). Bulk registration (3D) of planning and daily CT images gives global shifts. Slice-by-slice (2D) registration gives local shifts and rotations about the longitudinal axis for each axial slice. The daily MLC sequence is then created for each axial slice/MLC leaf pair combination, by taking the MLC positions from the pre-calculated plan with the nearest rotation, and shifting using a beams-eye-view calculation to account for local linear shifts.

A planning study was carried out using two MR images of a healthy volunteer, contoured to simulate a base-of-tongue treatment: One with the head straight (used to simulate the plan image) and one with the head tilted to the left (the daily image). **Results:** On a slice-by-slice basis, local rotations in the daily image varied from 2 – 31degrees. Local shifts ranged from -0.2 – 0.5cm and -0.4 - 0.0cm in right-left and posterior-anterior directions, respectively. The adapted treatment gave good target coverage, and kept the daily cord dose below the limit used in the original plan (65%, equivalent to 46Gy over 35 fractions). **Conclusion:** This technique may be useful for adaptive radiation therapy of targets where twisting around the longitudinal axis is significant. These results also demonstrate the feasibility of combining MLC sequences from different pre-approved treatment plans.

SU-FF-J-49

A Technique for Dose Reconstruction in Image-Guided Radiation Therapy

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Purpose: Images from volumetric CT-based image-guided radiation therapy (IGRT) can be used to reconstruct the doses delivered to the patient. The goal of this work was to develop a technique for data preparation and dose reconstructions for Megavoltage CT (MVCT) images acquired on a helical tomotherapy system. **Method and Materials:** MVCT images must be processed prior to dose reconstruction. The first step is for the MVCT images to be re-sampled to the dimensions of the kVCT images. The second step was to map the CT numbers (i.e. electron density) for the voxels within the MVCT data sets to match the kVCT CT numbers. Next, any missing data in the MVCT images (due to field-of-view limitations) must be padded with the data from the kVCT image set. The composite image set was then gaussian filtered. Finally, the treatment-planning cluster was used to re-compute doses based on the MVCT anatomy imaged during a particular fraction. **Results:** The goal of this work was to develop a system to perform dose reconstruction on MVCT images. A process was developed to match image dimensions, boundaries, resolutions and final completion of limited field of view. A custom program was then written that creates an input deck with the appropriate machine parameters, data files and treatment delivery sinogram for dose reconstruction. Dose reconstruction has been performed for prostate, head & neck, and lung cases. **Conclusion:** A technique has been developed to pre-process MVCT data and to perform dose reconstruction. **Conflict of Interest:** Research supported by TomoTherapy, Inc.

SU-FF-J-50

Assessment of Intrafraction Motion and Rotation During Head and Neck Treatments Based On 6D Analysis of Daily Stereoscopic Xray Imaging

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Purpose: To determine intrafraction motion and rotation of patients immobilized with a 5-point thermoplastic mask for head and neck treatments. **Method and Materials:** 13 patients were consecutively assigned to use a 5-point thermoplastic mask. Patients were positioned by tracking of infrared markers (IR) fixed to the immobilization device and stereoscopic Xray images were used for setup verification. Repositioning was carried out as needed, rotations were not corrected. Movements during treatment were monitored by real-time IR-tracking. Intrafraction motion and rotation was assessed by a 6-degree-of-freedom (6D) fusion of Xray images taken before and after all 385 treatments with DRR images generated from the planning CT data. The latter evaluates the patient's movement within the thermoplastic mask, where IR-tracking only evaluates the mask's movement. **Results:** The maximum intrafraction movement detected by IR-tracking showed a shift (mean (SD; range)) of 0.5(0.5; 3.8), 0.5(0.3; 1.9), 0.6(0.4; 3.3) mm in the vertical, longitudinal and lateral direction respectively and rotations of 0.2(0.1; 0.7), 0.2(0.1; 0.7) and 0.3(0.2; 1.0) degree about the vertical, longitudinal and lateral axis respectively.
The 6D fusions demonstrate intrafraction patient displacements of -0.5(1.2; 7.4), 0.3(0.7; 5.3), 0.0(0.7; 5.7) mm in the vertical, longitudinal and lateral direction respectively and rotations of -0.1(0.6; 4.1), 0.1(0.7; 8.3) and -0.2(0.8; 8.2) degree about the vertical, longitudinal and lateral axis respectively.
The standard deviations and ranges found with 6D fusion are significantly larger than detected by IR-tracking. This indicates the latter underestimates the magnitude of the actual patient's intrafraction motion and rotation. **Conclusion:** The 6D image fusion is a useful tool to evaluate the actual patient's intrafraction motion and rotation and shows the latter is not negligible. Thus, immobilization alone is not sufficient to allow narrow treatment margins. **Conflict of Interest:** This work was supported by BrainLAB AG Germany and Orfit Industries Belgium.

SU-FF-J-51

Auto-Regressive-Moving-Average Modeling of Respiratory Motion in Radiation Therapy

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Purpose: To construct a linear regression model of respiratory motion for prediction of future behavior from past records. Combined use of accurate respiration prediction and adaptive beams would ensure more accurate delivery of planned radiation, which is normally degraded due to patient breathing during treatment, especially for tumors in abdominal and thoracic regions. **Method and Materials:** Respiratory data were obtained by tracking a fiducial marker placed on the lateral chestwall of a female volunteer in supine position, using 2D dynamic MRI with a temporal resolution of 0.8 *sec/frame*. The data were analyzed using Auto-Regressive-Moving-Average modeling with the mathematical form $y_t + \sum_{i=1}^{p} a_i y_{t-i} = e_t + \sum_{j=1}^{q} b_j e_{t-j}$, where $\{y_t\}$ is the fiducial position with mean adjusted to zero, $\{e_t\}$ is the fiducial localization error assumed to be Gaussian white noise, p and q respectively represent orders of auto-regression and moving-average, and the $a_i's$ and $b_j's$ are autoregressive and moving-average coefficients. The model was identified as Auto-Regressive (AR), Moving-Average (MA), or Auto-Regressive-Moving-Average (ARMA) by visual inspection of the autocorrelation and partial-autocorrelation functions of $\{y_t\}$. The order(s) of the model, i.e. p and/or q, were determined by minimizing the *Akaike's Information Criterion (AIC) value*, a widely used goodness-of-fit measure compromising least-square fitting and number of parameters to be estimated. **Results:** A 5th-order autoregressive model was determined for the respiratory data. Qualitative observation of the actual and predicted breathing traces illustrated their similarity to each other. Quantitative analysis, which included autocorrelation function and histogram inspection of the prediction error, showed its randomness (uncorrelated in time) and small magnitude, indicating validity and reliability of the model. **Conclusion:** A prospective modeling and prediction method has been demonstrated for respiratory motion compensation in radiation therapy without prolonged treatment time. We will further test the approach on different volunteers and patients, with regular and irregular breathing traces.

SU-FF-J-52

Breathing Adapted Radiotherapy (BART) Using Modern Gating Technologies

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Purpose: The aim of this study was to evaluate the impact of the Varian RPM–gating™ System for gated treatment of breast cancer/thoracic wall cancer as well as Varian On-Board Imager™ (OBI) Fluoroscopic Pretreatment Setup Verification for gated treatment of lung cancers/upper intestinal tract cancers. **Method and Materials:** A passive, infrared light reflecting marker is placed on the patient's chest wall over the xiphoid process. The vertical motion of the marker, i.e. the breathing excursion, is tracked by an infrared sensitive video-camera-based hardware. The 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. The additional Fluoroscopic Setup Verification allows a fluoroscopy analysis of inner target movement with regard to a chosen therapeutic window of the RPM Gating system just prior to treatment. **Results:** Varian RPM-gating technology optimizes the dose delivery to regions with respiration-induced movements of the target. Safety margins and thereby irradiated critical volumes can be significantly reduced for breast cancer with RPM-gating as well as lung cancer with the OBI Fluoroscopic Pretreatment Setup Verification. **Conclusion:** Gating offers the possibility to apply doses with higher accuracy. As typical duty cycles are around 50% ore even 10%, the overall beam-on time is prolonged by a factor of up to 4. In order to compensate for this effect, a dose rate change from 300 to 600 MU/min when using enhanced dynamic wedges was chosen; in case of electronic compensation a dose rate change is not needed. The additional fluoroscopy mode offers for the very first time the possibility to verify patient positioning with regard to the moving target, which - for most cases – shows a phase shift relative to the RPM marker box movement.

SU-FF-J-53

Breathing Synchronized Irradiation Using Stereoscopic KV-Imaging to Limit Influence of Interplay Between Leaf Motion and Organ Motion in DMLC IMRT: Dosimetric Verification

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Purpose: Feasibility study of a prototype developed for breathing synchronized irradiation. **Method and Materials:** Adaptations to a commercially available image-guidance technique (NovalisBody/ExacTrac4.0, BrainLAB) have been implemented allowing gating. A simple phantom simulating a breathing pattern of 16 cycles/min and covering 4 cm has been introduced to assess the system's performance to: (a) Trigger the linac at the right moment (using a 3mm metal hidden target (HTT) mounted to the phantom). (b) Assess the delivered dose in non-gated and gated mode (using an ionization chamber (IC) mounted to the phantom). (c) Evaluate the interplay between organ and leaf motion in IMRT (using radiographic film mounted to the phantom). The effect of interplay has been evaluated by importing measured fluence maps, generated by the linac in non-gated and gated mode, into the treatment planning system (TPS) and re-calculate the resulting dose distribution. **Results:** No measurable delay in the triggering of the linac has been observed with the HTT. The IC measurements showed an improvement in dose absorption from 44% (non-gated) to 98% (gated) for small field irradiation (3x3 cm^2) of a moving target. Importing measured fluence maps actually delivered by the linac into the TPS yielded highly disturbed dose distributions with the non-gated delivery, whereas the gated delivery showed good agreement with the original theoretical dose distribution. These findings have been confirmed by the dose-volume histograms. **Conclusion:** First tests with the prototype for breathing synchronized irradiation showed promising results. The use of measured fluence fields, delivered by the linac in non-gated and gated mode, as imported fluence maps for the TPS revealed the impact of interplay between leaf and organ motion and the possibility of gating to resolve this issue. The latter should

be outweighed against increased treatment time. **Conflict of Interest:** Part of this work has been supported by BrainLAB AG

SU-FF-J-54

CCTV-Based Patient Setup Aids and Monitoring System in RT

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Purpose: To analyze patient motions as well as patient positioning during conventional radiation therapy, a radio frequency (RF)-based CCTV system with semi-beam's eye views (BEV's) is to verify patient setup.
Method and Materials: In order to capture patient images in semi-beam's eye views, 4 small cameras are installed in the blocking tray, which is mounted in the treatment head of linear accelerators: right, left, superior, and inferior oblique angles towards the isocenter of the linear accelerator. Each camera has its own 2.7GHz RF module (minimize the cross-talk interference between RF source of linear accelerator and the CCTV system), and transmits the signal to the receivers, which are placed in the wall of the treatment room. The semi-BEV images are monitored before and during irradiations and saved in the computer. The CCTV images and port films taken and analyzed in the first day, then are used as reference images. Also, a special laser with a point and a circle is attached in the tray to make a reference point for 4 cameras and a magnification factor (can be used as SSD meter) **Results:** The CCTV images are captured in semi-BEV's, thus very useful to compare the room lasers, cross hairs, and anatomical landmarks in patient contours. Because of wide dynamic range of the video amplifier, it can provide the patient images as well as room laser, and light field with room lights off. The radiation effects appear as a pepper and salt noise, which can be eliminated by employing averaging kernel in the computer. **Conclusion:** This CCTV system will be expanded to correlate with CT images in future and under progress. Also, the CCTV-based images will be connected to the internet, so that the doctors can be able to monitor patient setup in remote site.

SU-FF-J-55

Cumulative Dose Calculation Using Deformable Image Registration

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Purpose: To use deformable image registration to calculate cumulative dose distributions received by a radiotherapy patient in order to evaluate the dosimetric impact of anatomical variations during the course of treatment. **Method and Materials:** An intensity-based deformable registration algorithm was developed to register the anatomy between the planning CT image and the daily CT images acquired from an in-room CT-on-rails system. After the transformation from daily CT to planning CT was found, daily treatment doses delivered to an organ can be meaningfully accumulated. For one head-and-neck patient, the treatment plan was transferred to 15 daily CT scans using bony registration, and the dose distributions were calculated for the daily anatomy without daily setup errors. Using deformable image registration, these daily dose distributions were mapped back to the planning CT image. The cumulative dose was calculated and compared to the original plan using dose-volume histograms (DVHs). **Results:** The dose delivered to the patient had minimal changes from the plan. Dose coverage for clinical target volumes at 70Gy, 63Gy, and 56Gy, left and right parotids at 25Gy, and mandible at 70Gy were evaluated. At these dose levels, the DVHs showed less than 1% difference, except for the left parotid, which had a 6% volume difference. The maximum dose in brainstem was 1.4% less than planned, the maximum dose in spinal cord was 2.2% higher than planned. The mean doses in left and right parotid were 4.4% higher and 2.5% lower than planned. **Conclusion:** In this case, we found little dosimetric differences due to changing anatomy during the course of treatment. Future studies will include daily setup errors. Deformable image registration is proven to be an effective approach for calculating cumulative dose distributions delivered to the patient, which can be used to evaluate the quality of treatment execution.

SU-FF-J-56

Detecting Treatment Setup Errors for Head and Neck IMRT Patients with Multiple CT Scans

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Purpose: Conventional methods determine treatment setup errors in patients undergoing intensity-modulated radiotherapy (IMRT) by using orthogonal portal images that only detect translational errors. This study utilizes image-guided radiotherapy to develop and test an algorithm for detecting both translational and rotational setup errors in head and neck patients with multiple CT scans. **Method and Materials:** To confirm the accuracy of the proposed algorithm to detect translational shifts, it was tested using a constructed phantom with four embedded metal marks. Upon verification, ten head and neck patients with two temporally-independent CT scans were selected. For each patient, the translational and rotational errors were calculated by aligning selected bony landmarks from the two scans using matrix transformation with an incremental guess-check method. For comparison, the translational errors were also obtained by co-registering the two scans using the same landmarks with a commercial treatment planning system and comparing the isocenter of the second CT with that of the first CT. The contribution of the rotation to the translational error represents the difference between the translational shifts as computed by the algorithm and the conventional method. **Results:** The results of this study showed that the average magnitude of the rotational errors about the transverse, anterior-posterior, and longitudinal axes were $2.3° \pm 2.2°$, $1.3° \pm 0.9°$, $2.1° \pm 1.6°$, respectively. The average contribution of this rotation to the translational error in the left-right, anterior-posterior, and longitudinal directions were 3.1 ± 3.2, 2.0 ± 4.4, 4.4 ± 7.3 mm, respectively. In general, the greater the rotational error in the setup, the greater the subsequent translational difference between the methods. **Conclusion:** This study found that rotational errors do contribute significantly to the treatment setup error for head and neck IMRT patients. The proposed algorithm can detect these rotations and, consequently, more accurately determine the translations setup error.

SU-FF-J-57

Digital Tomosynthesis for Verification of Radiation Therapy Positioning: Preliminary Results From a Kilovoltage On-Board Imaging System

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Purpose: This study introduces a new radiation therapy target localization technique using online digital tomosynthesis (DTS), a method for reconstructing 3-D slices from 2-D projection data acquired with limited source motion. By separating the visualization of overlapping structure, DTS is expected to improve the visualization of anatomy compared with 2-D planar radiographic imaging techniques, and may therefore yield more accurate target localization during radiation therapy set-up. **Method and Materials:** We simulated treatment planning and setup of an anthropomorphic chest phantom. A treatment isocenter was marked in CT images. The phantom was then aligned for treatment on a Varian 21EX equipped with an on-board-imager (OBI), attached to the gantry orthogonal to the megavoltage treatment axis. Once aligned, 2-D image projections were acquired over 200 degrees and coronal and sagittal DTS planes were reconstructed through the treatment isocenter from projection sub-sets spanning 40º. Comparison of DTS images with corresponding planes from the CT data, as well as lateral and postero-anterior (PA) planar radiographs, yielded estimations of set-up error. **Results:** Sagittal and coronal DTS slices improved the visibility of anatomy when compared with planar radiograph equivalents, improving estimation of the set-up error. Registration of sagittal and coronal DTS reconstructions with corresponding planes through the isocenter in the CT data was found to be feasible for estimating set-up error. Preliminary determination of the set-up accuracy of our clinical procedure was determined to be within 1mm for the phantom study presented here. **Conclusion:** Tomosynthesis has been demonstrated on a commercially available medical accelerator, and may be practical for improving patient set-up when full cone-beam-CT is not required. DTS significantly improves the visibility of soft-tissue detail that is obscured by overlying anatomy in radiographs and portal images. Additional benefits include a reduction in dose, acquisition and reconstruction time, and easier data handling compared with full cone-beam-CT.

SU-FF-J-58

DMLC Leaf-Pair Optimal Control for Mobile, Deforming Target

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Purpose: Tumors in the lung and abdomen tend to move and deform during the course of respiratory cycle. To deliver the intensity modulated therapy, in which intensity map dynamically shifts and deforms in conjunction with the target motion, algorithms have to be developed that control appropriately leaf progression in DMLC IMRT. Description of such algorithms is the purpose of this presentation. **Method and Materials:** Target motions and deformations are simulated by analytic, periodic functions dependent on position and time. Derived infinitesimal relationships between leaf velocities at all leaf positions assure delivery of the predetermined intensity map. Derived formulas lead to a system of interdependent ordinary, differential equations. When minimization of time of DMLC IMRT delivery is required equations are uniquely defined by scalar fields that are determined by intensity function, target local velocities and target local parameters of deformation, together with constraints on maximum leaf speeds. Integration of differential equations provides trajectories for MLC leaves and thus determines the algorithm for relevant DMLC motion controls. **Results:** A representative example of DMLC IMRT delivery to deforming target is presented. The example shows the delivery of analytically defined double parabolic intensity function to target undergoing oscillatory type deformation. Target deformation is assumed to be spatially uniform. Deformation of the target, as well as trajectories of leading and following leaves, are calculated and graphically represented for this example. The snapshots of leaf positions at various stages of intensity delivery are also shown. **Conclusion:** Algorithms are developed for the control of MLC leaf motions that make possible delivery of DMLC IMRT to targets experiencing deforming motions. These realizations of IMRT therapies to deforming targets prevent any discrepancies, rooted in target's dynamic distortions during treatment, between intended and actual intensities delivered to the target.

SU-FF-J-59

Dose Calculation and Quantitative PTV Expansion Using Dynamic MRI Images

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Purpose: To extend the geometrically defined PTV expansion for lung cancer patients to dosimetrically relevant PTV expansion by incorporating dynamic MRI into dose calculation and to quantitatively compare the dosimetry of uniform PTV dose with the dosimetry of non-uniform PTV dose for a moving tumor. **Method and Materials:** A 1.5-T whole-body Siemens MRI scanner was used in the experiment. The patient diagnosed with metastatic adenocarcinoma at lower right lobe was scanned by trueFISP (true Fast Imaging with Steady Precision) sequence. The tumor was contoured from the first frame and automatically tracked by normalized correlation and snake for the rest frames. Dynamic MRI images were rigidly registered to the CT images and the dose images from tomotherapy. Under the assumption of invariant dose distribution for slightly changed anatomy, accumulative dose and DVH for the target was calculated by convolving moving target volume with the dose image. In order to compare non-uniform does distribution and uniform dose distribution, a 10% does boost was added to the superior/inferior end of the PTV dose when calculating the cumulative dose. **Results:** No significant dose fall off was observed when the craniocaudal (CC) PTV expansion reduced from 11 mm to 8 mm. The cold spot of tumor dose became noticeable when the CC expansion reduced to 7 mm and was substantial at 5mm. Compared with uniform PTV and 7 mm CC expansion, a 10% dose increase at the CC ends of the 5 mm CC expansion achieved same quality of dose distribution and reduced average lung dose for 7.1%. **Conclusion:** By incorporating dynamic MRI into dose calculation, the estimate of appropriate PTV expansion is more dosimetrically relevant and accuracy. With accumulative dose calculation and a specific patient, non-uniform PTV dose shows superior quality than the conventional uniform dose. Generalization of this conclusion is under further investigation.

SU-FF-J-60

Effectiveness of MVCBCT for Patients with Implanted High-Z Material

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Purpose: To exploit the penetrability of high-energy photons of Megavoltage ConeBeam CT system (MVCBCT) to obtain 3D images of the anatomy in presence of "Non-compatible CT" objects made of high-Z material. **Methods and Material:** A new MVCBCT system integrated onto a clinical Linac was used to acquire 3D images of different phantoms and patients. The grey levels of different electron density inserts (lung to dense bone) in a CT phantom were measured with and without the presence of a small Cerrobend rod (10x15mm) on a regular CT and with the MVCBCT. MVCBCT of a Rando phantom with implanted gold markers and tooth fillings as well as patients with dental implants or with gold markers implanted in prostate were also obtained. **Results:** The presence of the Cerrobend object in the CT phantom scanned with a regular CT creates strong artifacts around the object and disturbs the quality of the entire image, modifying the Hounsfield numbers by an average of 10%, even 15 cm away from the rod. The grey levels of the density inserts in the CT phantom remain unchanged within 3% in presence of the Cerrobend rod for MVCBCT. Similarly, gold markers appear with the typical star pattern artifact on CT images where a well-defined dot is seen on MVCBCT. The tooth fillings in the MVCBCT Rando phantom do not disturb the soft tissue information around the teeth. **Conclusion:** Compared to the kV energy range, the presence of high-Z material has relatively little impact on image quality of MVCBCT. Therefore, MVCBCT can complement missing information for planning or patient position verification purposes when high-Z materials such as gold markers, tooth fillings, dental implants or hip prostheses are present. Clinical examples of each of these items will be presented. **Conflict of Interest:** Siemens supports this Research

SU-FF-J-61

Evaluation of Two Fluoroscopic Imaging Setups for Online Dose Delivery Adaptation

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Purpose: One aim of ART is the observation of organ motion followed by a subsequent adaptation of the treatment plan. Two imaging configurations were evaluated for their potential of online tracking and correction of organ motion by using fluoroscopic images: x-ray tube in line with a flat panel detector mounted at (A) 90 or (B) 180 degree offset to the MV-beam. **Method and Materials:** For one lung case two IMRT plans with 5 beams were optimized for two MLCs with 10mm and 2.75mm leaf width. The motion of the target was modeled by a rigid transformation. Respiratory motion in the lung was investigated for different amplitudes. The dose distributions for different cases (no-movement, uncorrected movement, correction for the movement perpendicular to the monitoring kV-beam) were evaluated. **Results:** For the simulated movement with a small amplitude (3mm) in the AP direction the dose distributions resulting from the correction of the displacement vector using system (A) or (B) showed similar results independent of the collimator. They were in good agreement with the dose distribution of the static (not moving) patient. Increasing the amplitude in the AP direction to 6mm or even 9mm leads for both amplitudes and both MLCs to almost the DVHs of the static dose distribution if system (B) is used for the online correction. For the dose distribution resulting from the correction based on system (A) the difference between the static and the corrected doses is continuously increasing especially for the more conformal static dose distribution of the 2.75mm MLC. **Conclusion:** For motion amplitudes up to 6mm both systems can create dose distributions similar to the static dose distribution. For increasing amplitudes in the AP or LR direction the imaging system (B) will create dose distributions equal or superior to system (A). **Conflict of Interest:** Research supported by Siemens-OCS.

SU-FF-J-62

Image-Guided Radiotherapy Feasibility Study Using Kilo-Voltage Cone-Beam CT Images for Patient Alignment Verification

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Purpose: The objective of this work was to evaluate the feasibility to acquire the kilo-voltage (KV) cone-beam computer tomography (CBCT) images and to register the CBCT images with the conventional planning CT images for patient alignment verification. **Method and Materials:** A Varian high precision accelerator with on-board KV imaging (OBI) system and CBCT was used in conjunction with a QA head phantom for patient setup position verification. In addition, the in-house image registration and verification software was used for the analyses of patient alignment accuracy. First, we acquired the same reference image data sets of the QA head phantom from the CBCT and the LINAC/CT-on-rails unit. The conventional CT image set was used as the planning CT images. Applied the translation and/or the rotation to the QA head phantom to imitate the daily patient setup variation and then, acquired the daily CBCT images. **Results:** No differences were observed on the registration between the reference image sets obtained from the conventional planning CT and CBCT. Similar findings were also observed on the registration of the daily CBCT with the planning CT images when the translations were applied to the setup of the daily QA head phantom deviated from the planning QA head phantom setup. When the rotations were applied to the daily setup of the QA head phantom, the treatment target was registered well between the daily CBCT images and the planning CT images, but the difference of 1.3 mm was observed on the registration in the structure relatively far away from the target. **Conclusion:** Phantom studies indicated that the daily pretreatment CBCT images should be suitable to use for patient alignment verification with the planning CT images. **Conflict of Interest:** supported by Varian Medical Systems.

SU-FF-J-63

Improved Dose Accuracy for On-Line Adaptive Radiation Therapy Using Deformable Dose Registration

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Purpose: The time available for dose evaluation in daily on-line adaptive radiotherapy scenarios necessitates the use of fast correction-based algorithms such as pencil beam (PB) algorithms, but precludes the use of accurate Monte Carlo (MC) algorithms. This study proposes to improve PB dose accuracy by utilizing deformable image registration techniques in a process called deformable dose registration (DDR): MC results on a deformed patient anatomy are approximated based on an MC calculation on a reference anatomy and the deformation field of the PB calculations between the reference and current anatomies. **Method and Materials:** A 5×5 cm^2 6-MV AP beam incident upon a thoracic CT image set $I_0(\mathbf{x})$ was computed with both PB and MC dose-calculation algorithms resulting in $D_0^{PB}(\mathbf{x})$ and $D_0^{MC}(\mathbf{x})$. A thoracic case was chosen because of known inaccuracies in the radiological path-length correction of PBs for lung heterogeneities. The same treatment beam was then computed on a deformed data set, $I_1(\mathbf{x})$, to obtain $D_1^{PB}(\mathbf{x})$ and $D_1^{MC}(\mathbf{x})$. Treating $D_0^{PB}(\mathbf{x})$ and $D_1^{PB}(\mathbf{x})$ as images, the (Discrete Cosine Transform) DDR operator $\overline{\mathbf{U}}_{0\to1}(\mathbf{x})$ was determined that transformed $D_0^{PB}(\mathbf{x})$ to $D_1^{PB}(\mathbf{x})$, $D_1^{PB}(\mathbf{x}) = D_0^{PB}(\overline{\mathbf{U}}_{0\to1}(\mathbf{x}))$. $D_0^{MC}(\mathbf{x})$ was then transformed to $I_1(\mathbf{x})$ using $D_0^{MC}(\overline{\mathbf{U}}_{0\to1}(\mathbf{x})) = \hat{D}_1^{MC}(\mathbf{x})$ ($\wedge$ indicates an estimated dose distribution). Dose distributions were compared to determine if $D_1^{PB}(\mathbf{x})$ or $\hat{D}_1^{MC}(\mathbf{x})$ better predicts $D_1^{MC}(\mathbf{x})$ based upon isodose contours, dose differences, distance-to-agreement, and gamma-analysis. **Results:** Isodoses for $\hat{D}_1^{MC}(\mathbf{x})$ better predicted $D_1^{MC}(\mathbf{x})$ than those from $D_1^{PB}(\mathbf{x})$. The mean dose difference for $\hat{D}_1^{MC}(\mathbf{x})$ is zero, while for $D_1^{PB}(\mathbf{x})$ it is ~-3%. Using a 3%, 3 mm criteria, 70% of $D_1^{PB}(\mathbf{x})$ agreed with $D_1^{MC}(\mathbf{x})$ with $\gamma < 1.0$, while 92% of $\hat{D}_1^{MC}(\mathbf{x})$ had $\gamma < 1.0$ indicating that $\hat{D}_1^{MC}(\mathbf{x})$ is a better predictor of $D_1^{MC}(\mathbf{x})$ than $D_1^{PB}(\mathbf{x})$. **Conclusion:** Using DDR techniques with fast PB results to estimate a more accurate algorithm's dose improves overall dose accuracy compared with using the fast PB algorithm alone. Such techniques may be useful in on-line adaptive radiotherapy scenarios where dose accuracy is required, but dose calculation time is limited. (Work supported by NIH-R01-CA98524)

SU-FF-J-64

Influence of Respiratory Motion On Cone-Beam CT (CBCT) Imaging of Thorax and Abdomen

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Purpose: To quantify the interplay between respiratory motion and CBCT imaging in thoracic and abdominal region. **Method and Materials:** A Varian Acuity CBCT simulator was used to scan a motion-simulation phantom and three patients (a pancreatic and two lung cases). Motion phase of the phantom or the patients was stamped with a Varian RPM system. For phantom study, three CBCT gantry rotation speeds (5^o, 10^o, and 15^o per second) were used. Several different motion patterns and speeds of the phantom, simulating a variety of clinical situations, were also investigated with CBCT gantry speed of 10^o/s. The patient scans were done with10^o/s rotation speed. The resultant images were compared against the 4D-CT images acquired on a GE LightSpeed scanner. The HU profiles of the two types of images were analyzed. **Results:** Given the fact that a regular breathing cycle takes ~4s, a CBCT scan is usually a time-average over ~10 breathing cycles. Large artifacts and anatomical distortions were observed in both phantom and patient scans. In the phantom study, the onset of motion artifacts started at very low "breathing" motion rate, suggesting that CBCT is less proof against motion. The CBCT image quality was worsen as the "breathing" rate increased but this became saturated when the phantom motion rate reached to a certain level. For the patient study, the discrepancies between the CBCT and 4D CT images were also found to be large. The tumor contours, for example, delineated based on the two types of images can differ up to 1cm **Conclusion:** Respirator motion greatly degrades the quality of CBCT and presents a problem in thorax and abdomen imaging. It is urgently needed to develop a clinically practical means to minimize the adverse effect of breathing motion.

SU-FF-J-65

Intrinsic Accuracy of I-Beam's Coordinate Positioning System Technology

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Purpose: I-Beam, a 3D-ultrasound guided prostate localization system, uses Coordinate Positioning System (CPS) Technology in registering live ultrasound images of the patient to the treatment machine coordinate system. The goal of this study is to verify the accuracy of I-Beam's camera system and its precision in localizing the US images to the isocenter. **Method and Materials:** The first part of the study was to examine the I-Beam camera system for integrity in tracking the probe position while translating the US probe in 3D-space. We then examined alignment correctness when registering the captured US images and contours. A robotic arm of the Nomos BAT system was used for accurate translations. Both the arm and camera system were fixed to the treatment couch. Longitudinal translations of the camera system were confirmed by the Nomos Auto-crane. An ultrasound phantom mimicking pelvic anatomy was employed in quantifying the precision of the image localization and contour alignment. The phantom was translated to known distances, recapturing the 3D-ultrasound volume, and aligned the contours to determine the shifts computed by the I-Beam system. **Results:** X-, Y- and Z- translations recorded by the robotic system were subtracted from the coordinates of the camera system in computing the errors. When the camera system was repositioned within ±10 cm of the 3D-space, the CPS technology predicted the ultrasound probe position within ±0.5 mm. The absolute deviations were (mean ± SD): 0.3±0.2, 0.2±0.2 and 0.2±0.2 in lateral, longitudinal and vertical directions, respectively. I-Beam's image registration and contour alignment were accurate within ±1mm. **Conclusion:** The I-Beam camera system is accurate to within ± 0.5mm in tracking the US probe position. Phantom measurement showed the US image acquisition and the contour alignment is also accurate within ±1mm. These new tests assured that the I-Beam system is accurate in tracking, image-registration and alignment.

SU-FF-J-66

Iso-NTCP Dose Escalation with Image-Guided Adaptive Radiation Therapy (IGART) for Localized Carcinoma of the Prostate

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Purpose: To evaluate the efficacy of various image-guided target localization techniques to assist in the safe dose escalation for prostate cancer radiation therapy in the presence of geometric uncertainties. **Method and Materials:** Five prostate cancer patients were analyzed, retrospectively. All patients were planned with an 18MV six-field conformal technique with a 10 mm margin and an initial prescription dose of 70 Gy in 35 fractions. For the dose escalation study, the prescription dose was increased from 50 Gy in 2 Gy increments until the rectum normal tissue complication probability (NTCP) reached the level equal to that of the plan NTCP (i.e., iso-NTCP). The target localization techniques simulated were (1) laser alignment to external tattoo marks, (2) alignment to bony landmarks with daily portal images, and (3) alignment to the clinical target volume (CTV) with daily CT imaging. Techniques (1) and (3) were re-simulated with a reduced margin of 5 mm to investigate further dose escalation. **Results:** The selection of the target localization technique was less critical on the treatment outcome when 10 mm margin was used. Reducing the margin size from 10 to 5 mm effectively decreased the NTCP by ~ 60 % for all patients. For iso-NTCP dose escalation, to our surprise, the average dose and TCP gain for the five patients were largest with the external tattoo technique (6.4 Gy and 7.5 %, respectively) followed by the daily CTV and the bony landmarks. The variability in gain across the five patients, however, was also largest with the tattoo registration technique and smallest with the daily CTV technique. **Conclusion:** Based on these data, the best dose escalation strategy is to combine margin reduction (for increased normal tissue sparing) with the use of the daily CTV technique to localize the target volume (for consistent dosimetric coverage and escalation).

SU-FF-J-67

Monte Carlo Dose Calculation in Prostate Patients Aided by 3D Ultrasound Imaging

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Purpose: To investigate the use of Monte Carlo (MC) dose calculations for improved assessment of the daily treatment dose for prostate patients using novel 3D ultrasound imaging. **Method and Materials:** Prostate displacements were measured in 39 prostate cancer patients undergoing external-beam radiotherapy with a 3D ultrasound image guided radiotherapy system (RESTITU, Resonant Medical Inc). The system resides in both the CT-Sim and treatment rooms. It acquires 3D ultrasound (US) data of the pelvic region just prior to the CT-sim, with the 3D US image registered in absolute space. Subsequent 3D US images are also acquired before treatment delivery, resulting in a set of 3D US images of the time-evolving geometry. The system also calculates prostate displacement between the CT-Sim and treatment data sets. An algorithm was developed to combine CT images in a MC dose calculation system with 3D US information such as organ shifts and contours. Dose distributions for both shifted and unshifted CT data were calculated using both a conventional planning system (CADPLAN) and a MC dose calculation system. **Results:** MC calculated dose distributions in prostate patients were found to differ significantly from conventional dose calculations using the CADPLAN system, mainly due to the influence of the femoral heads. Incorporation of the 3D US measured prostate shifts in the MC dose calculations clearly show severe tumour underdosage would result if no correction was applied to the patient setup. When correcting the patient setup, calculations taking the time-evolving 3D US contours into account show that significant differences in the dose distributions in the target and surrounding tissue occur compared to a single planning dose calculation. **Conclusion:** Ultrasound information from a 3D US system opens up the possibility to obtain improved dose assessments for daily treatment fractions using MC dose calculation techniques, leading eventually to image-guided adaptive radiotherapy.

SU-FF-J-68

Motion-Compensation in IMRT Employing Probability Distribution of Target Location: Phantom Tests and Computer Simulation

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Purpose: To investigate potential utility of the probability density function (PDF) of target location in managing the detrimental effect of target motion on the delivered dose distribution. **Method and Materials:** Recent advances in 4-D imaging allowed for a more detailed and precise observation and description of internal organ motion due to respiration. Realistic average target trajectories and corresponding PDF were obtained from the analysis of 4D-CT data. It was assumed that these motion patterns were stable and reproducible during treatment delivery. Dose calculation and treatment plan optimization were performed with a modified "motion kernel", obtained by superimposing pencil beam doses delivered to different instances of anatomy (phases of motion), or, in the first approximation, through convolution of the generic pencil beam kernel with the PDF of target location. With this approach, sample motion-compensated plans were optimized and delivered in fractions to a movable phantom, which reproduced preset motion patterns in two dimensions. Dose measurements were performed with diagnostic film for the linac rates of 100, 300 and 500 MU/minute. Robustness of treatment plans with respect to delivery errors and variations in target motion, as well as interplay with the MLC leaf movement, was further investigated in a computer simulation. **Results:** While optimized fluence patterns showed deviation of as much as 50% between standard and motion-compensated plans (for 2-cm peak-to-peak amplitude of target motion), the doses delivered in a single fraction deviated by less than 15% point-by-point, and were within 3% of prescription after 30 fractions (reduced approximately as the inverse square root of the number of fractions). **Conclusion:** Phantom tests showed that the use of motion kernel for treatment planning allowed maintaining the conformality of dose distribution delivered over multiple fractions, without expanding planning margins beyond the CTV.

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SU-FF-J-69

Pitch, Roll and Yaw Device for Helical Tomotherapy Head & Neck and Brain Treatment

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Purpose: To demonstrate the effectiveness of a new pitch, roll and yaw device for helical Tomotherapy head and neck and brain treatment. **Methods & Materials:** The pitch, roll and yaw device is a headrest frame with a mechanism for adjusting angular orientation. It is fabricated using two overlaying Lucite panels mounted on an adjustable wheel base. With the use of the pitch, roll and yaw headrest device three MVCT image sets are obtained, and two displacement adjustments (first angular, second translational) are made. Since the axis of rotation may not be located in the center of the image volume, adjustments for the rotational and translational displacements have to be made independently. The rotational adjustments are made after the first scan, and the translational adjustment is made after the second scan. A third MVCT scan is obtained for final verification prior to treatment. **Results:** Using the headrest device, on average the pitch, roll and yaw angular displacements can be reduced to less than 0.2º, 0.3º, and 0.25º, respectively, after three MVCT scans. The final translational x, y, z, displacements are still be minimized to less than 1mm after rotational adjustments. **Conclusion:** As a mechanism for adjusting angular displacements, the pitch, roll and yaw device provides additional degrees of freedom for target localization. However, one additional MVCT image set is needed in order to independently adjust the rotational and translational displacements.

SU-FF-J-70

Respiratory Gated Radiation Therapy Directly Using Patient's Fluoroscopic Images Instead of External Or Internal Markers

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Purpose: To develop a respiratory gated radiation therapy (RGRT) technique by directly matching the patient's anatomical structures acquired during the imaging cycles to that in a reference image. **Method and Materials:** Studies showed that the external markers and the internal treatment volume are not always well correlated during the RGRT. Here we propose to measure the correlations of a reference image to the fluoroscopic images acquired during the breathing cycles. Such correlation measurement can be the surrogate for the external markers. A threshold of the correlation can be used to trigger the linear accelerator (Linac) for RGRT. With the capability of acquiring fluoroscopic images from the on-board imaging (OBI) device developed by Varian, this approach becomes available. In this study, we measured the correlation coefficient (cc) and the root mean square (rms) error of the reference image to the on-line fluoroscopic images. **Results:** In order to do efficient gating, the calculation of the correlation of one image to the reference should be 1-10ms and this can be easily achieved in our preliminary study. Also, the correlation can be better calculated by sparsely sampling the calculation pixels around the treatment volume rather than using a local ROI inside the volume. In the former, we found that both the cc and the rms demonstrated good periodicity. As we expected, the external marker locations recorded by the RPM software not always correlate well with the cc and rms. **Conclusion:** We demonstrated that RGRT by matching the patient's anatomical structures is highly feasible. The reference image can be the one from a gated fluoroscopic image or DRR from a gated CT scan. This technique will allow both gating and tracking and can be significant for high dose high-precision radiation therapy with reduced margins for moving targets.

SU-FF-J-71

Shifting MLC Shapes to Adjust for Daily Motion of the Prostate in the Concurrent Treatment of Pelvic Lymph Nodes and Prostate

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Purpose: To determine if adjusting the multileaf collimator (MLC) leaf positions to follow daily motion of the prostate is a feasible alternative to moving the patient, and to apply this adaptive strategy to concurrent treatment of the prostate and pelvic lymph nodes **Method and Materials:** A leaf-shifting algorithm was proposed to adjust MLC leaf positions to follow prostate movement while keeping the MLC portal shape unchanged. The MLC shift for each segment was calculated based on the beam direction, and the direction and magnitude of prostate movement. A computer program was written to implement this algorithm. The shifted MLC shapes were subsequently imported back into a commercial treatment planning system for the final dose calculation. For prostate-only plans, isodose distributions were compared between the shifted MLC plans and shifted isocenter plans, which mimic the adjustment of patient position. For plans including the prostate and pelvic lymph nodes, isodose distributions were compared between the partially shifted MLC plans and shifted isocenter plans. **Results:** For prostate-only plans, the isodose distributions were the same for shifted MLC positions and for shifted isocenters. For pelvic lymph node plans, shifting patient treatment position to follow prostate movement significantly reduced the dose coverage to the pelvic lymph nodes. Shifting MLC leaves associated with the prostate while keeping the MLC leaves associated with the lymph nodes unchanged resulted in improved dose coverage to both the prostate and the pelvic lymph nodes. **Conclusion:** Shifting MLC portal shapes is equivalent to shifting patient treatment position. In order to concurrently treat the prostate and pelvic lymph nodes, with the prostate moving independently, shifting the MLC shape is a better adaptive strategy than shifting the patient. **Conflict of Interest :** Research supported in part by Siemens

SU-FF-J-72

The Effect of MV Cone-Beam CT Cupping Artifacts On Dose Calculation Accuracy

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Purpose: MV cone-beam (CB) CT imaging can be used to position the patient prior to external-beam radiotherapy. If calibrated, these images may also be used in dose calculations, opening the possibility to reconstruct the delivered dose or re-optimize the treatment plan before delivery. This study investigates the effect of imaging artifacts on dosimetric accuracy. **Method and Materials:** Two water cylinders of 13 cm and 22.5 cm diameters were imaged using A) a MV CBCT system integrated with a Siemens accelerator and B) a conventional kV CT imager. Cupping trends observed in the MV CBCT were imposed on the kV CT images to create artificial data with simulated artifacts. Using the Phillips Pinnacle planning system, a 6 MV 10 x 16 cm^2 field was applied to 1) the original kV CT of the smaller cylinder and 2) the kV CT with simulated artifacts. Similarly, a 18 x 18 cm^2 field was applied to the original and artificial kV CT of the larger cylinder. **Results:** For the smaller cylinder, the MV CBCT water signal relative to air at the cylinder center differs from the radial and axial extremities by approximately 14% and 17% respectively. For the larger cylinder, the differences are 38% and 20% in radial and axial directions. The dose distributions for the artificial images show a systematic deviation which increases with depth. In the high-dose, low-gradient regions, the largest deviation for the smaller cylinder is 1% of the maximum delivered dose. For the larger cylinder, the largest deviation is 4%. **Conclusion:** Cupping artifacts in water phantoms produce dosimetric errors much smaller in magnitude than the cupping trend itself but as large as 4% for large phantoms. These results suggest that rough correction of MV CBCT artifacts may be sufficient for dosimetric accuracy. **Conflict of Interest:** Research supported by Siemens OCS.

SU-FF-J-73

Treatment Simulation for 4D Image Guided Radiation Therapy

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Purpose: To investigate the feasibility of a dynamic treatment simulation system, PortSim[+] for four-dimensional image guided radiation therapy (4DIGRT) and respiratory gated Intensity Modulated Radiation Therapy (RGIMRT). **Method and Materials:** PortSim+ is an in-house developed software package that allows for simulation of 4DIGRT and RGIMRT. The software is integrated with our conventional simulator. Prior to simulation, a set of DRRs at different respiration phases along with the corresponding anatomic contours were imported from the treatment planning station. The respiratory rhythm and cycle of the patient is captured using a radio-opaque marker which reflects the circumference change of a binding belt around patient's chest. The marker correlates with the respiratory cycle and can be easily detected. In 4DIGRT simulation, the displayed reference DRR and corresponding MLC is triggered by the respiratory cycle. Similarly for RGIMRT, the MLC overlay is linked to the respiration phase and duty cycle threshold. Once the dynamic MLC characteristics are accounted for, both 4DIGRT and RGIMRT can be simulated prior to delivery in order to ensure that patient is positioned accurately and the treatment is delivered as planned. **Results:** PortSim[+] incorporates live acquisition of high quality fluoroscopic images (1024 x 1024), image intensifier distortion correction, breathing phase detection, reference DRRs and MLC display. The software runs on a Pentium IV 2.2 GHz, with 1G RAM computer. Initial results show that the system can successfully detect the breathing cycle and sequence the display and superposition of DRRs and dMLC. The complete simulation can be recorded at a rate of 30 frames per second for later review and analysis. **Conclusion:** The initial experience with this system indicates that uncertainties in set-up and delivery of 4DIGRT and RGIMRT treatment can be greatly reduced. The recorded simulation provides information that could influence field design and plan development.

SU-FF-J-74

Tumor Motion and Tumor Shape Changes During Radiotherapy of Bladder Cancer

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Purpose: First, to quantify bladder tumor motion in three dimensions. Secondly, to relate the motion to changes in bladder filling. Thirdly, to evaluate shape and volume changes of the GTV during the course of the

radiotherapy. **Method and Materials:** CT images were obtained for 21 bladder cancer patients. Next to the planning CT scan, each patient underwent 8 to 11 follow-up CT scans. These scans were matched on the bony anatomy. Patients were instructed to empty their bladder and drink 250 cc water one hour prior to acquisition. Tumor, bladder and rectum were delineated manually. For each patient, the variation in tumor position (day-to-day tumor motion) was determined by calculating the shift of the center of gravity (CG) of each GTV relative to the mean CG. These shifts were compared with model results from a previous study, concerning patients with a healthy bladder. The correlation between bladder volume and GTV position was determined. To study GTV shape changes, we matched all GTVs and determined the residual shape errors in terms of SDs. **Results:** Tumor motion was largest in Cranial-Caudal and A-P direction and ranged from 0.1 to 0.9 cm. The movement was strongly correlated with the bladder filling and the tumor location on the bladder wall. The average SD of the GTV shape changes, excluding the 10% highest values, ranged from 0.1 to 0.35 cm. The SD of the GTV volume ranged from 0.5 to 13 cc and was not dependent on the GTV volume. We found no significant volume time trend. **Conclusion:** We demonstrated that, despite large differences in bladder filling, variations in GTV shape were small. We could not prove any GTV volume trend with time. Geometrical uncertainties of the GTV position were mainly caused by variation in bladder volume and depended strongly on the GTV location.

SU-FF-J-75

Geometric Calibration of An Extended View C-Arm Platform for Cone-Beam CT

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Purpose: A mobile C-arm with a versatile detector mount (providing extended field-of-view) has been developed for multi-mode fluoroscopy and cone-beam CT image-guidance of surgical procedures. Geometric calibration estimating a set of parameters that fully describe the geometry of the systems is essential for the accurate image reconstruction and precise surgical guidance. We have developed a general analytic method to calibrate this system. **Method and Materials:** The platform for the extended view C-arm for Cone-beam CT is a Siemens PowerMobil. Field of view can be extended originally from 18x24 to 18x40 cm^2 with the computer controlled linear guide system attached to the arm to displace the position of the imaging detector. It allows imaging objects such as pelvis of patients on C-arm. The calibration phantom, modified to fit in the field of view, consists of 16 ball bearings precisely located in two circular trajectories in a cylindrical plastic phantom. All the geometric parameters including source position, and detector position and rotation with respect to gantry angle are found at various detector shifts. The calibration algorithm previously developed and verified at the cone-beam CT systems on optical bench and clinical linear accelerator was applied. **Results:** The uncertainty of the calibration algorithm is less than 0.6^o (out of plan) and 0.01^o (in plan) in detector angles, 0.01mm (normal to the beam direction) and 1.4mm (beam direction) in x-ray source/detector position. Repeatability of the center of the detector in various gantry angle and detector shift was less than 1 pixel size. Optimal weight of the counter valance for precise motion of the extended view C-arm was also found using the calibration parameters. **Conclusion:** Overall, a robust method has been developed for an accurate geometric calibration of systems demonstrating non-ideal trajectory. This will allow an accurate cone-beam CT reconstruction and manual/robot-assisted image guided surgical procedures.

SU-FF-J-76

Minimally-Invasive Intraoperative Radiotherapy (MIR): Technique Development for Treatment of Canine Bladder Cancer

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Purpose: To develop, model, and quantify the dose reduction on critical structures using Minimally-Invasive Intraoperative Radiotherapy (MIR) for the treatment of canine bladder cancer, and develop the technique for laparoscopic placement of the custom tissue expander. **Method and Materials:** A custom tissue expander was constructed and implanted between the bladder and descending colon of three Beagle cadavers. Two of the implants were placed via laparotomy, and one was laparoscopically placed. The cadavers were positioned in a body fix mold, and CT scanned with the custom tissue expander inflated with saline solution and deflated. A radiation therapy treatment plan was constructed on the tomotherapy treatment planning system for the inflated and deflated CT scans of each cadaver. TLD chips were placed on the bladder and colon side of the laparoscopically placed tissue expander. Pre-treatment target localization was accomplished by using the onboard MVCT of tomotherapy. Both inflated and deflated treatment plans for one fraction of the laparoscopically placed cadaver were delivered. **Results:** Keeping the dose to the bladder fixed, the average dose reduction when the tissue expander is inflated for the colon is 42.7%, spine is 38.7%, left kidney is 50.52%, and right kidney is 31.9%. A significant maximum dose reduction to these structures is also achieved. TLD chip measurements on either side of the inflated tissue expander showed a dose reduction of 55.1%. **Conclusion:** The cadaver studies evaluated indicate the potential for a clinically significant dose reduction to the colon, spine, left and right kidneys using MIR. An effective laparoscopic technique was developed to allow for the quick placement of the custom tissue expander in the abdominal cavity with minimal incisions. **Conflict of Interest:** This work was partially supported by a grant from the NIH (P01 CA088960) and a contract from TomoTherapy Inc.

SU-FF-J-77

Implementation of Averaged 4D CT Imaging for Extracranial Stereotactic Radiation Therapy

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Purpose: To implement Averaged 4D CT imaging to measure the motion of lung tumor during breathing **Method and Materials:** Averaged 4D CT images are obtained by averaging 4D CT images. A Philips Brilliance 16P CT scanner is used to obtain 4D CT images. The scanner acquired 16 parallel slices per couch position and 25 cinematographic images per slice to produce a ciné image set. The corresponding images are then averaged at each slice. All averaged images are assembled longitudinally to produce a series of Averaged 4D CT images, whose pixel value therefore contains the information about the movement of the target anatomy. An egg-shaped object and a block-shaped object were used for testing. A few patients were also studied and evaluated. **Results:** Phantom results showed that Averaged 4D CT images could accurately record the movement of a target having a natural breathing frequency. Results with lung tumor showed that Averaged 4D CT images gave a significantly larger GTVs resulting in larger PTVs, compared with helical CT images. Both the phantom and patient results clearly showed fuzzy areas as a consequence of moving anatomy. The time needed for creating an Averaged 4D CT image set from original 4D CT image set with 5 cinés and 400 slices per ciné is about 370 seconds. **Conclusion:** This technology can be accurate and practical for approximating the location of moving anatomy if used properly. Therefore, Averaged 4D CT images can replace helical CT images for radiation planning and treatment purposes with the advantage that they have greater precision than standard helical scans. **Conflict of Interest::** Part of this work was funded by Elekta, Inc., Norcross GA.

SU-FF-J-78

Evaluation of Setup Accuracy for Hypofractionated Radiotherapy of Liver Using Portal Imaging and On-Line KV Fluoroscopy

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Purpose: To compare image-guided accuracy for stereotactic radiotherapy of the liver in terms of reproducibility and targeting confidence. **Method and Materials:** The study involved eight patients treated for inoperable liver metastases or hepatobiliary carcinoma. Each treatment fraction, these patients were imaged and repositioned using orthogonal portal images acquired in AP and lateral views. Repositioning occurred when the measured offset exceed 3mm in any of the cranio-caudal (CC), anterior-posterior (AP), and medio-lateral (ML) directions. A second pair of orthogonal images assessed the residual setup accuracy. Orthogonal fluoroscopy sessions, each lasting 30 s, were acquired; some prior, but most after radiotherapy delivery. All images were acquired with the patient under active breathing control. All treatments were performed using a conventional medical linear accelerator equipped with a kilovoltage x-ray source and flat-panel detector mounted at 90 degrees from the linac beam

central axis. The right diaphragm was used as a surrogate for the liver position. The reproducibility and stability of the diaphragm was thus analysed for a total of 48 fractions. **Results:** After initial setup and repositioning, the residual setup error determined from portal images was 2.6 (CC), 3.0 (AP), and 2.6 mm (ML); conversely, the residual setup error measured from the kilovoltage fluoroscopy sessions was 3.2 (CC), 3.1 (AP), and 2.1 mm (ML). **Conclusion:** Daily portal imaging and repositioning based on these images improves setup accuracy. Similar accuracy is shown from kilovoltage fluoroscopy analysis. On-line fluoroscopy can potentially assess patient position prior and after delivery of radiation therapy, and provide a baseline for cone-beam CT analysis. **Conflict of Interest::** This work is supported, in part, by Elekta Radiation Oncology. LD is supported by an ASCO career development award

SU-FF-J-79

Local Tomography Using Adapted Feldkamp and Expectation Maximization Algorithms

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Purpose: There has been much interest utilizing megavoltage CT to verify patient positioning in conformal radiation therapy. Local tomography methods have been proposed for reconstructing tumor volumes. In this work, we use simulated and experimental phantom projection data to investigate and compare 3D local tomography approaches based on the Feldkamp-Davis-Kress (FDK) and Expectation Maximization (EM) reconstruction algorithms. **Method and Materials:** We have implemented numerically local tomography versions of the EM and FDK reconstruction algorithms. An ensemble of numerical phantoms was created that contained structures of varying size and contrast. Multiple noisy simulated data sets were computed. Untruncated experimental projection data corresponding to a head and torso phantom were also acquired. From these data sets, truncated data were created by keeping only subsets of the complete data. 3D images of the tumor volumes were reconstructed by use of the local FDK and EM algorithms. The reconstructed images were assessed visually to determine if the boundaries and interfaces within the tumor volume were reconstructed accurately. The contrast of the reconstructed boundary information was quantified. **Results:** For the low-noise data sets that contained a large number of uniformly spaced projections, the local FDK algorithm produces images that had better boundary contrast than those produced by the EM algorithm. However, the EM algorithm reconstructed images with reduced artifact levels when the projections contained high noise levels and were few in number. **Conclusion:** In many applications of MV CT, the number of truncated projections is limited. In these cases, the EM is more appropriate than the FDK algorithm for reconstructing geometric information regarding the tumor volume. However, the local FDK algorithm is better suited for reconstructing low contrast boundaries when the number of acquired projections is sufficient.

SU-FF-J-80

Clinical Procedures for Daily Patient Setup Verification Using On-Board Imager (OBI)

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Purpose: The newly installed OBI system consists of a kilo-voltage (KV) X-ray source and a flat- panel detector mounted orthogonally to the megavoltage portal imager (MV) in Varian 21EX machine. These devices are linked to the OBI workstation which provides a platform for acquisition/analysis of images and auto couch motion for repositioning the patient. This paper presents our clinical procedures for patient setup verification using OBI. **Method and Materials**: In phase I, two sets of orthogonal MV/MV and KV/KV images were acquired to confirm the accuracy of the KV system by comparing daily KV images to traditional MV images and corresponding Digital Reconstructed Radiographs (DRRs). The phase II study acquired only one set of orthogonal MV/KV portal images for daily patient setup verification. An anterior MV and lateral KV images were obtained without gantry rotation. The OBI workstation provided the tools to match the images with DRRs and to analyze the shifts to be made for patient setup correction based on either implanted and/or anatomical markers. The treatment couch was moved automatically based on this analysis. Post-shift MV/KV images were acquired to reconfirm patient positioning. All images and positioning data were electronically saved and reviewed. **Results:** Four prostate IMRT patients were included in phase I study. The isocenter alignment of the two sets of images (MV/MV and KV/KV) was found within 2mm relative to DRRs during the entire treatment courses. The phase II study included 30 prostate IMRT patients. The review of post-shift MV/KV images showed an average of 2 mm deviation relative to DRRs. All procedures could be completed within 3-5 minutes. **Conclusion:** Phase I study proves that KV images are as reliable as MV portal images with better image quality. Phase II study verifies that matching/analysis tools and auto-couch motion provide fast and accurate patient positioning.

SU-FF-J-81

Clinical Integration of a MV Conebeam CT System for Image-Guided Treatment

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Purpose: To perform the integration of a newly developed image-guidance system and to describe the main advantages and performance of the first Megavoltage Conebeam CT (MV CBCT) system. **Method and Materials:** The MV CBCT system, consisting of a new a-Si flat panel adapted for MV imaging and an integrated workflow application allowing the automatic acquisition of projection images, conebeam CT image reconstruction, CT to CBCT image registration and couch position adjustment was recently introduced in clinic. Template protocols can be used for the acquisition of CBCT images at different dose ranging from 1 to 60 M.U. Geometrical calibration, gain image adjustment and defect pixels correction procedures are performed off-line. **Results:** For a typical case, 200 projection portal images and a total exposure of 5 to 8 M.U. are acquired with the 6 MV beam in 45 seconds and the 256x256x256 MV CBCT image is reconstructed less than two minutes after the start of the acquisition. Examples of the image-guided treatment process including the acquisition of projections images, the reconstruction of the MV CBCT image and its registration with the planning CT, followed by the couch position correction and dose delivery will be presented. **Conclusion:** MV CBCT provides a 3D patient anatomy volume in the actual treatment position, relative to the treatment isocenter, moments before the dose delivery, that can be tightly aligned to the planning CT, allowing verification and correction of the patient position.

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SU-FF-J-82

Use of CT Based IGRT for Daily Set-Up of Frameless Fractionated Stereotactic Patients

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Purpose: To compare orthogonal port films against CT based Image Guided Radiation Therapy (IGRT) for patient isocenter verification and assess the use of CT based IGRT for daily patient set-up.

Method and Materials: Eleven patients with brain metastases were CT'd for each of their fractionated radiosurgery treatments. The patients were immobilized in the supine position with a stereotactic head cast. Two of the patients had a bite block in their cast to minimize rotational movement. The daily CT was taken on a SOMATON Emotion Duo CT on rails and the treatment was delivered by a SIEMENS PRIMUS linear accelerator (linac). The daily CT images were then fused to the planning CT using fiducial markers and anatomy as guides. The shifts in the X, Y, and Z directions were computed by the Coherence Dosimetry Workstation and the patient was shifted accordingly to within 1 millimeter accuracy. **Results:** We assessed the accuracy of the orthogonal port film technique against the CT based IGRT for 8 frameless stereotactic treatments. The implementation of IGRT increased the importance of patient immobilization while decreasing the need for accurate initial patient set-up since the patient would be imaged immediately prior to treatment and corrections could then be made to the set-up. Furthermore it was observed that using a bite block inside the head cast significantly improved patient immobilization and decreased the magnitude of IGRT shifts. **Conclusion:** Orthogonal port film validation of

the isocenter is adequate for an accuracy of 5mm for frameless stereotactic treatments. CT based IGRT provides an adequate verification of the isocenter for frameless stereotactic treatments to within 2-3mm accuracy . Furthermore, CT proves to be of clinical benefit to the patient since the mean dose used for each CT was only .7cGy where port films use 3cGy each for the two orthogonal images.

SU-FF-J-83

Use of CT-Simulation Tools Located On the CT Scanner for Localization Guidance in Extracranial Stereotactic Radiotherapy: A Feasibility Study

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Purpose: To quantify the accuracy of CT-simulation localization tools located on the CT-scanner control console for guidance in extracranial stereotactic radiotherapy (ESRT). **Method and Materials:** ESRT applies stereotactic treatment principles to irradiate extracranial tumors in few fractions (typically 2-6) with high dose/fraction. To accomplish this, an anatomic reference coordinate system is replaced by an external stereotactic coordinate system and improved patient immobilization methods are also used. Because the patient is scanned prior to each treatment while in the immobilization device, it may be possible to use a low-sag (<1mm at 250lbs) CT couch and CT-simulation tools in place of the stereotactic coordinate system. With adequate immobilization, use of the CT-simulation tools may allow implementation of this technique at institutions where a stereotactic frame and specialized ESRT software are not available. Four ESRT patients, for a total of twelve treatment fractions, were scanned in a body frame on a CT-simulator equipped with CT-simulation localization tools prior to each treatment. Treatment isocenter coordinates were determined based on target volumes contoured by the physician using the stereotactic frame and specialized ESRT software. A second set of treatment coordinates was determined based on the same contours using the CT-simulation software. The two sets of coordinates were compared to quantify the accuracy of CT-simulation method. **Results:** The maximum, mean, and standard deviations between the CT-simulation and stereotactic coordinates for the twelve treatment fractions in X (left/right), Y (anterior/posterior), and Z (cranio/caudal) directions in millimeters were (X_{max}=1.1, X_{mean}=0.5, X_{SD}=0.4), (Y_{max}=1.2, Y_{mean}=0.3, Y_{SD}=0.3), (Z_{max}=2.5, Z_{mean}=1.1, Z_{SD}=0.8). CT study voxel dimensions in X, Y, and Z directions were 0.94mm, 0.94mm, and 3.0mm. **Conclusion:** The excellent agreement between the CT-simulation and stereotactic coordinates indicates that CT-simulation tools with appropriate immobilization can be used for target localization or independent verification in ESRT.

SU-FF-J-84

Accuracy and Feasibility of Cone Beam Computed Tomography (CBCT) for Stereotactic Radiosurgery (SRS) Setup

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Purpose: To investigate the accuracy and feasibility of cone beam computed tomography (CBCT) for stereotactic radiosurgery (SRS) setup. **Method and Materials:** A stereotactic BRW frame was attached to a Rando head phantom with imbedded radio-opaque markers (1mm in diameter) simulating the target locations. The head phantom with a CT localizer was first simulated for radiosurgery planning on a conventional CT scanner and then scanned on a treatment machine using CBCT. The differences between the conventional and CBCT localizations of the target positions were computed using a radiosurgery planning software. The translational corrections for target positions were calculated as the differences between the CBCT coordinates of the machine isocenter and the planned isocenters, which were the planned BRW coordinates from the conventional CT scan multiplied by the transformation matrix between the BRW and CBCT coordinate systems on the CBCT scan. The setup accuracy of CBCT was assessed from the analysis of orthogonal projection images for each radio-opaque target at the machine isocenter. **Results:** All nine fiducial markers of BRW localizer were successfully identified on all but one slice of the CBCT scan. The average localization difference between the conventional CT and CBCT BRW target coordinates was 0.28mm (SD 0.10mm). The mean distance error for all the radio-opaque targets localized using the CBCT and orthogonal projection images was 1.28mm (SD 0.61 mm). The major contributing factor to this cumulative setup error was the uncertainty in the superior-inferior direction due to the 2mm slice thickness in conventional CT. **Conclusion:** The CBCT image guidance can be used to setup SRS patients within accuracy comparable to the current SRS standard using an external fiducial system. The technique described here can serve as a gold standard for evaluating the accuracy of alternative immobilization and setup devices for SRS.

SU-FF-J-85

Automatic Seed Detection in MVCT Images for Prostate Radiotherapy

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Purpose: In radiotherapy treatment of prostate, a common approach to prostate localization for each treatment fraction is to insert several seeds into the prostate as a marker. The seeds are visually identified and aligned by the radiation therapist prior to treatment. Manual seed identification and registration is a time-consuming process, and the precision of the seed localization is on the order of voxels. We developed an algorithm that can detect the seeds automatically and achieve sub-voxel precision. **Method and Materials:** The CT number of the MVCT images was calibrated by matching their histogram to the reference KVCT image histogram. An edge-preserving image smoothing filter was applied to MVCT images of prostate. This filter can effectively remove the noise while preserving the edge of organs and seeds. After the noise was reduced, the images were scanned and a connected-threshold method was used to label isolated high-CT-number regions. These regions include seeds and bone structures. A seed classifier was designed based on the size and the mean CT-number of the region. The position of the seed was determined with sub-voxel accuracy by calculating the mass center of the seed assuming the CT-number corresponding to the mass density. The entire process is fully-automatic. **Results:** The algorithm was tested on 39 MVCT images, each containing three seeds. It achieved over 90% success rate in the detection of all three seeds without false-positive. When we restrict our search range within a box that encases the prostate, we achieve 100% success rate. **Conclusion:** We have demonstrated a fully-automatic, high-precision seeds detection algorithm that works very well in MVCT prostate images. The performance can be further improved if the MVCT image quality is better, or if we confine the seeds searching area to the prostate location.

SU-FF-J-86

Megavoltage CT Image Characterization, Quality, and Enhancement

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Purpose: The use of Image-Guided Radiation Therapy (IGRT) has increased dramatically over the past five years. The purpose of this work was to evaluate quality of Megavoltage CT (MVCT) image and to develop methods for image enhancement. Method and Materials:
The accuracy of MVCT imaging was measured using repeat imaging of an anthropomorphic head phantom in a known geometry. A technique for improving Image quality was developed using stable iterative deconvolution technique that utilizes that obtains an estimated inverse linear filter for a given instrumental response function or point spread function.
The investigators also developed a technique for reconstructing 4D MVCT images. Image data was collected axially with the couch stationary during the imaging of each slice. The detector data was over-sampled to capture different phases of respiration. The data corresponding to each projection was then re-binned data and reconstructed for each phase of the respiration cycle Results: The Tomotherapy image-guidance software yielded total imaging system errors of ±0.6 mm, ±0.5 mm, and ±0.6 mm with the automatic image fusion algorithm set to “Bone”, “Bone and Soft Tissue”, and “Full-Image” respectively. Deconvolution image enhancement was performed on MVCT images of a prostate patient sharpened high contrast landmark. This increased the contrast resolution of bone, bowel gas, and soft tissue. 4D image reconstruction was also used to eliminate motion artifices from motion phantom. Conclusion: The MVCT images acquired on a helical tomotherapy delivery system have the positional accuracy to position the dose distributions to within 1-mm of the desired position using the current clinical system. Deconvolution image enhancement has been used to improved superior-inferior contrast resolution, and respiration

artifacts have been corrected with retrospective 4D image reconstruction. **Conflict of Interest:** Research supported by TomoTherapy, Inc.

SU-FF-J-87

Linac Based KV Cone-Beam CT for Extended Field of Views: Evaluation of An Approximate Reconstruction Strategy

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Purpose: To evaluate an approximate image reconstruction method for a kV-cone-beam CT system with an increased field-of-view (FOV) obtained by an asymmetric detector placement. **Method and Materials:** An approximate reconstruction method for width-truncated projections based on projection weighting was implemented and tested on both synthetic and real CT-projection data. Real data were taken with a 40.96cm x 40.96cm (1024x1024 pixels) flat panel detector, which was shifted by 8.4cm from its central position to achieve an asymmetric detector design corresponding to a detector width of 57.76cm, increasing the theoretical FOV at the isocentre-plane from 28.8cm to 40.7cm. For the tests on real data an anatomical phantom of the abdomen and a spherical contrast phantom with inserts of different densities and differently sized holes were used. With synthetic data created for a cylindrical contrast phantom, the quality of the reconstructed images was examined for larger distances from the central slice and for different detector offsets (8.4cm, 12cm and 16cm), corresponding to FOV sizes of 40.7cm, 45.7cm and 51.4cm. **Results:** For the spherical contrast phantom, the measured absorption coefficients differed on average by 3% from those obtained in the normal cone-beam reconstruction, with a slightly higher standard deviation. The spatial resolution was equally good.
The anatomical phantom showed good results for the internal structures, with the outer contours missing because of detector saturation effects.
For synthetic data, deviations in measured density increased with larger detector offset (from 1.4% to 2.7% in the central slice) and with larger distance from the central slice (up to 3.1% at z = 12.2cm for a 16cm detector offset). **Conclusion:** The investigated method to increase the FOV in cone-beam CT showed promising results both on synthetic and real data. The achievable FOV allows for full-size images even of the extra-cranial region. **Conflict of Interest:** Research supported by Siemens-OCS

SU-FF-J-88

Portal Imaging Capability of Motion Detection

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Purpose: Quantitative determination and validation of tumor motion is required for Image-Guided Radiotherapy (IGRT) of mobile tumors. One method for validating motion is portal imaging using electronic portal imaging devices (EPIDs). Ability to detect and delineate moving tumors depends on EPID specifications and image acquisition protocol. Requirements include accurate object definition and the capability to localize objects throughout the breathing cycle, at different locations within the body. We devised a straightforward test to assess EPID performance. **Method and Materials:** Water-filled spheres of different diameters were attached to a computer-controlled linear stage programmed to move spheres at constant velocities over a range of distances (up to 60mm) and speeds (from 5-40mm/s), within a stationary phantom. Images were captured during motion cycles using Varian PortalVision and Elekta iView amorphous silicon EPIDs. Accuracy of the projected target position was evaluated for images consisting of 1-3 averaged frames. We tested the image quality across the EPID while maintaining fixed source-to-object (isocenter) distances. **Results:** Both imaging systems accurately reproduced projected target shapes. The accuracy of range and speed measurements were 0.5mm and 0.1mm/s, respectively. The iView system detected the 60mm range of motion to within 2.5mm, for all tested speeds. The PortalVision system detected 60mm range of motion to within 3.5mm, up to 20mm/s, but performance degraded at greater speeds, with images missing in parts of motion cycles. At 30mm/s, only 45mm was detected. For both systems, range measurement errors were proportionally smaller for shorter ranges. Both imagers performed consistently throughout their imaging surface and both were comparable for image quality. **Conclusion:** We've devised a process that can simultaneously assess motion detection capability and test EPID systems. Both imagers performed well in static conditions, implying accelerator feedback system led to missing images. We'll investigate methods to improve the dynamic imaging characteristics of these EPID systems.

SU-FF-J-89

MV Portal Imaging with Sub-MU Exposure

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Purpose: To acquire megavoltage portal images for radiation therapy verification with less than 1 MU. **Method and Materials:** Portal images were acquired using the 6 MV beam from a Varian 2100 EX accelerator and a prototype Varian 4030HE electronic portal imager (EPID). The EPID has an 8mm thick, pixelated CsI scintillating layer, allowing good quality images with less than 1 MU. A synchronization circuit reduced the dose to one beam pulse/image (up to 30 images/s can be acquired). Image noise was improved by averaging several images. We acquired images of an aluminum contrast-detail (Las Vegas) phantom and calculated the contrast-to-noise ratios of the indentations in it. The noise inside an open field was plotted as a function of the number of averaged frames. We also acquired weekly gated orthogonal localization images of the thorax for five lung cancer patients for physician review. **Results:** Good quality images were acquired with an average of 10 one-beam-pulse images, corresponding to 0.3 MU. The CNS of the portal images of the Las Vegas phantom using the 4030HE and 0.3 MU was as good as that using the aS500 and 4 MU; the noise levels in the open field were also the same. Image quality and discernibility of of anatomic features in the patient images were deemed by the physician to be comparable to those from a standard 4MU portal image. **Conclusion:** The new EPID can produce portal images with the same quality as the aS500, with a fraction (0.3 MU) of the dose conventionally used (usually 4 MU/image in our department). The imager also works with the Varian RPM respiratory gating system, allowing us to acquire gated portal images for verification of respiratory gated radiotherapy. This work was supported in part by U.S. National Institutes of Health grant P01-CA59017 and by Varian Medical Systems.

SU-FF-J-90

An Accurate Method for Determining Prostate Shift and Rotation Using Portal Images with Implanted Fiducial Seeds

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Purpose: Portal imaging of implanted fiducial seeds is widely used for setup verification of conformal radiotherapy for prostate cancer. Isocenter shift is usually determined by the shifts of two imaging fields required to align the fiducials to their planned positions. Due to prostate rotation, deformation and seed migration, it might not be possible to satisfactorily align the fiducials. We describe here an accurate image-processing method to determine the isocenter shift and prostate rotation using three fiducial seeds. **Method and Materials:** Two portal images were obtained using anterior-oblique beam angles for clear seed imaging. The center of a portal image was determined by field edges. The images were enhanced for seed identification by filtering operations. The 3-D coordinates of the seeds were determined considering their physical dimensions and the signal strength of processed images. The three seed-to-seed distances were checked to avoid using a migrated seed for setup verification. The Triad algorithm was used to find the rotation of the plane of the three seeds to make it exactly parallel to the reference seed plane. The seeds were then shifted and rotated about the common normal vector to the seed plane by iterations for a least-square fit of imaged and planned seeds. **Results:** The method was tested on 10 cases with daily portal images. The largest isocenter shift and seed plane rotation were 2 cm and 13 degrees, respectively. The isocenter shifts determined by aligning the seeds on individual images with split differences led to larger than 2 mm errors. The seed-to-seed distance was reduced on average by 3-4 mm, indicating the prostate was shrinking during the treatment. **Conclusion:** An accurate method was developed for determining the shift and rotation of the prostate using portal images, in order to minimize the errors due to lacking the 3-D correlation of fiducial seeds.

SU-FF-J-91

Assessment of Prostate Position During External Beam Treatments for Patients Post Brachytherapy Implantation

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Purpose: To localize the prostate for patients undergoing an external beam boost after receiving an I-125 implant to within 3mm and confirm the position of the prostate post-treatment using marker seeds implanted in the prostate as a surrogate for its position. **Method and Materials:** Twenty patients receiving an I-125 prostate implant had three marker seeds implanted in the prostate during the procedure. After the implant the patients underwent a CT simulation for an external beam radiotherapy boost. The marker seeds were contoured and projected onto a DRR with a reference field. Prior to each treatment, radiation therapists imaged the patient with an EPID. The therapists then localized the seeds relative to reference field and determined the error in the alignment of the prostate. If the alignment error was greater than 3mm in any one direction the patient was shifted and re-imaged to verify the shift. A portal image was acquired after the patient's treatment to confirm the position of the prostate post-treatment. **Results:** Averages and standard deviations for pre-treatment prostate alignment error ranged from -0.10 ± 0.18 to 0.15 ± 0.14 cm, -0.13 ± 0.16 to 0.16 ± 0.16 cm, and -0.17 ± 0.24 to 0.14 ± 0.19 cm in the right/left, superior/inferior, and anterior/posterior direction, respectively. Averages and standard deviations for the difference between the pre-treatment and post-treatment prostate alignment error ranged from -0.13 ± 0.08 to 0.09 ± 0.16 cm, -0.12 ± 0.18 to 0.21 ± 0.26 cm, and -0.15 ± 0.17 to 0.09 ± 0.15 cm in the right/left, superior/inferior, and anterior/posterior direction, respectively. **Conclusion:** Pre-treatment the prostate was localized to within 3mm using markers seeds implanted in the prostate and an EPID. Post-treatment portal images confirmed the prostate position to be within 3mm of its pre-treatment position.

SU-FF-J-92

Dosimetric Comparison of Skin, Bone, Ultrasound, and CT Alignments for Prostate Cancer

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Purpose: To quantify the dosimetric impact of four alignment methods (skin marks, bone, ultrasound, and CT) on the daily treatment of prostate patients. **Method and Materials:** Six prostate patients received 3 CT scans per week immediately before treatment using an integrated CT-linear accelerator (135 CT scans total). We simulated the delivery of the clinical treatment plan by re-aligning the plan on each CT scan using four techniques. The alignments used skin marks, bony registration of the CT scans, ultrasound, and prostate center-of-volume (COV). To compare the dosimetric effects of these alignments, we collected dose-volume histograms of the prostate, seminal vesicles, bladder, and rectum. **Results:** These six patients could be divided into a stable group (3/6 cases) with average anterior-posterior prostate motion $\leq$ 2mm, and an unstable group (3/6 cases) with motion $\geq$ 2mm. The stable group showed minimal dosimetric changes with the four alignment techniques. For the unstable group, the average minimum prostate dose (to $1cm^3$) was 75.6Gy with prostate COV, 72.3Gy with ultrasound, 67.2Gy with bone, and 65.4Gy with skin. The variation in daily minimum prostate doses was smallest with prostate COV alignment. Ultrasound alignment also reduced the daily variation except for two patients with large gas. For one case where the prostate tended to move anteriorly, re-alignment decreased the rectal dose while increasing the bladder dose. For two cases where the prostate moved posteriorly, the reverse occurred. **Conclusion:** Patients can be separated into two groups based on the average prostate motion. Patients with average anterior-posterior prostate shifts above 2mm can improve their prostate coverage by using ultrasound (better than skin and/or bone) or prostate COV (best) alignment techniques. Rectal doses will increase with posterior prostate motion. More than one CT scan is required to determine if a particular patient will significantly benefit from ultrasound and prostate COV alignment.

SU-FF-J-93

Treatment Dose Verification for Image-Guided Stereotactic Radiotherapy of Lung Cancer

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Purposes: The purpose of this work is to retrospectively verify treatment dose delivered in patients treated with stereotactic radiotherapy (SRT) to the lung. **Method and Materials:** In this study, a stereotactic body localizer (SBL) system was used for lung cancer patient immobilization in the CT simulation and stereotactic treatment planning on a prospective dose escalation protocol for malignant lung tumors. Prior to each treatment, a localization CT san was obtained in the treatment room after the patient was immobilized in the SBL. The stereotactic coordinates of three pre-selected bony landmarks were recorded from the pre-treatment scan and compared with those of the planning scan. Couch shifts were made based on the bony-landmark displacements. Image fusion was performed between the simulation CT scan to each pre-treatment CT scan in order to obtain the same planning target volumes (PTVs) and critical structures. 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 normal structures for the old and new isocenter coordinates using the bony-landmark shifts. 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 preliminary study for 6 patients with 20 dose reconstructions showed that the average D_{95}, D_{99}, and V_{95} of the PTVs are 95.9%, 93.6%, and 98.4% of the planned values before bony-landmark shifts. With the bony-landmark shifts, these values are all improved to 100% of the planned values. The average V_{20} and V_{30} are 7-8% higher than the planned values without bony-landmark shifts and recovered the planned values after the corrections. **Conclusion:** With near real-time 3D image guidance for setup error correction, the delivered dose distribution can be ensured for SRT hypofractionated lung treatment.

SU-FF-J-94

Comparison of Analytic and Iterative Algorithms for Image Reconstruction in Gated Megavoltage CT

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Purpose: To assess and compare the merits of analytic and iterative algorithms for reconstructions of 3D images from gated megavoltage (MV) projection data that are non-uniformly sampled in projection angle. **Method and Materials:** 2D projection images are acquired in a full fan cone beam geometry using the 6MV beam from a Varian 2100 EX accelerator and a prototype Varian 4030HE electronic portal imager. Because a respiratory gating system is used to confine radiation delivery to a predetermined part of the respiratory cycle, the projection image sets containing angular gaps of varying length. This non-uniform angular sampling of the projection data can be expected to result in image artifacts when an analytic reconstruction algorithm is employed. We compare two different methods, a filtered backprojection (FBP) algorithm and the expectation maximization (EM) method, for reconstructing 3D images of phantoms and patients from gated cone-beam MV projection data. Several data sets are considered that contain different sized gaps in the angular sampling of the cone-beam projections. The quality of the reconstructions is assessed by calculating contrast to noise ratios (CNRs) of inserts in an electron density phantom and by observer preference. **Results:** The CNRs are consistently higher in the images reconstructed by use of EM algorithm. This can be attributed to the lower noise and artifact levels in the images. The computational burden of the EM algorithm is large, but it may be reduced considerably by use of the ordered subsets expectation maximization (OS-EM) version of the algorithm. **Conclusion:** The EM reconstruction algorithm produced 3D images with reduced artifact levels and higher CNRs than those in images produced by the FBP algorithm. Iterative reconstruction methods can significantly improve image quality in gated MV CT applications, but is not suitable for immediate clinical use without implementation on high-performance computers or dedicated hardware.

SU-FF-J-95

Comparison of a Center-Of-Volume Contour-Based Alignment and a CT Image-Based Automatic Alignment of Prostate Target in CT-Guided Radiotherapy

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Purpose: Due to organ deformation, the validity of using center-of-volume (COV) for prostate alignment has not been evaluated against other approaches and vice versa. The goal of this study was to compare two methods of prostate target alignment: one used manually delineated contours and the other used a combination of automatic and manual image registration method. **Method and Materials:** In an IRB-approved protocol for repeat CT imaging using a CT-on-rails system, 15 patients received 3 CT scans per week over a period about 8 weeks. For each of the 353 CT images, the prostate was manually contoured by two radiation oncologists and checked by one of them. The center of volume (COV) was computed based on the gravity center of the contour containing the prostate. A CT-Assisted Targeting (CAT) software was also developed in-house for on-line CT image-guided radiotherapy. The registration algorithm consisted of cost functions that were designed to provide accurate, robust and automatic detection of the prostate. The daily position of the prostate was calculated using both the COV method and the CAT software. For the later, the results were also reviewed in every CT images and adjusted when necessary. **Results:** The mean differences (±1SD) between COV and CAT alignments were -0.2±0.9 mm, -0.4±1.5 mm, and 0.7±2.4 mm in lateral(RL), anterior-posterior(AP), and superior-inferior(SI) directions, respectively. The results of alignments were highly correlated ($p<0.0001$) in all directions. Although large differences are few, an outlier analysis showed that large differences were due to (1) inter-observer variation in contouring the reference CT and the daily CT (61%), (2) large deformations of anatomy (65%), and (3) the combination of both (45%). **Conclusion:** We found that both the COV method and the CAT alignment agreed well to within 2mm in RL, 3mm in AP, and 5mm in SI for 95% of alignments.

SU-FF-J-96

The Application of Varian's Markermatch Software in a Retrospective Study of Inter-Fractional Prostate Motion

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Purpose: MarkerMatch is an automated marker match software feature developed by Varian in on-board imaging. It may calculate inter-fractional prostate motion with internal fiducial markers identified on CT scans. Before each treatment, a pair of portal images was taken and fiducial markers are identified. Based on the portal image pair, MarkerMatch calculates the optimized couch displacement in 3D to maximally restore the marker positions to their reference positions. To evaluate MarkerMatch's clinical performance, we did a phantom test and a retrospective study on patients implanted with radio-opaque fiducial markers. **Method and Materials:** We used a phantom implanted with 4 cylindrical-shaped markers of 1mm in diameter and 3mm in length. MarkerMatch localizes the markers based on CT images. In order to test MarkerMatch's ability to handle CT images of different quality, we scanned the phantom with four CT spacing. The portal image pair taken before treatment is normally at AP/Lateral gantry angles, but sometimes it is difficult to identify markers from the lateral image. To test MarkerMatch's ability to handle non-orthogonal portal image pair, we took portal images at 7 different gantry angles. As a preliminary test for the use of Markermatch in clinic, we retrospectively analyzed five patients implanted with 2-3 gold markers based on 43 pairs of weekly setup portal images. **Results:** In our phantom test, MarkerMatch is able to measure overall marker displacements within 1mm in each direction, regardless of the spacing used in the CT scans. Using different gantry separation angles, the measured overall marker displacements agree with each other within 1mm. Retrospective analysis of five patients is also presented. **Conclusion:** Initial studies indicate that MarkerMatch is robust in detecting and analyzing patient motion in 3D and can provide valuable information of inter-fractional prostate motion in clinic. **Conflict of Interest:** Funded in part by Varian Research Grant.

SU-FF-J-97

A Novel Metric for Automatic Assessment of Deformable Image Registration Accuracy

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Purpose: The purpose of this research is to develop a metric that automatically assesses the accuracy of deformable image registration by evaluating the difference in voxel values and the minimum distance to agreement between the predicted and actual images. **Method and Materials:** A metric, κ, has been developed, which is based on two parameters 1) difference in voxel value and 2) minimum distance to voxel agreement. Voxels within the predicted image, or a selected subregion within the region, are randomly selected for evaluation. Each voxel is assessed to determine if it is within 3 image units (i.e. Hounsfield Units or MR number) of the voxel value on the actual image or within 0.3 cm of its corresponding voxel on the actual image. The κ index indicates the percentage of points passing at least one of the parameter.
The correlation between κ and the error in the image was established by introducing known random error into an image. Mathematically deformed CT and MR data was generated for analysis (mean = 0 – 0.5, SD = 0 – 1.0 cm). **Results:** Although the metric can overestimate the percentage of points meeting the criteria, due to similar voxel values in the search region, a unique correlation was established between the effective error in the image with known deformation and κ. A power law relationship between described 98% of the variance between the known error and κ. This relationship was then used to assess the error in deformable image registration using a finite element based method. The results show good agreement with prior manual accuracy evaluation. **Conclusions:** A novel metric, κ, describing the error in deformable image registration has been investigated providing a unique correlation between κ and the residual error in registration. **Conflict of Interest:** This research was supported in part Varian Medical Systems.

SU-FF-J-98

Feasibility of Deformable Structure Registration Towards Calculation of Cumulative Dose Distributions

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Purpose: Cumulative dose distribution in fractionated radiation therapy is one means to evaluate the risk of complications. Yet the calculation of the distribution is highly challenging due to inter-fraction change in anatomic geometry. This work presents an algorithm for deformable image registration of bladder and cumulative dose calculation in the setting of HDR brachy-therapy for vaginal cylinder treatment. **Method and Materials:** CT scans were obtained on 20 patients with gynecological cancer who received fractionated high dose rate brachy-therapy 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 and its surface was extracted for input to a biomechanical deformable registration algorithm, which models the structure surface as a thin elastic sheet. Three anatomic correspondence points were identified for each fraction. In three patients we observed additional identifiable landmarks against the bladder wall. These extra markers as shown in each fraction were compared with their predicted location based on both the affine and deformable registration. **Results:** Compared to the bladder volume at the time of the first fraction, the ratio of the bladder volumes for later fractions ranged from 30 to 300%. Rigid and affine registration of the bladder showed poor correlation of the landmark locations. The deformable registration algorithm significantly improved the accuracy of the correlation. While validation was possible for only three patients, eight independent tests were done for different fractions. **Conclusion:** The deformable registration algorithm provides a means of tracking points on structures despite significant change in size and shape. While further validation is needed, this approach provides a means to calculate cumulative dose distributions that were not previously feasible.

SU-FF-J-99

Automation of Image Registration and Verification for Image-Guided Stereotactic Body Radiotherapy

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Purpose: To facilitate image-guided stereotactic body radiotherapy (SBRT) with high precision and fully automated target localization and patient position verification. Method and Materials: A mutual information based image registration algorithm was developed to register the patient's daily 3D computed tomography (CT) images with those taken for treatment planning to assess and correct patient position shifts in all three translational and three rotational directions. A digitally reconstructed radiograph (DRR) algorithm generates and displays the corresponding DRRs in one frame in a split screen format along with their intensity differences to enhance verification. In the same way, the portal image verification algorithm processes the portal image and displays it with the corresponding planning DRR in the same frame as final verification of the patient's position. The algorithms were programmed using MatLab and were assembled seamlessly in one package and the operation was fully automated. Results: Target localization and patient position verification process in our image-guided SBRT is significantly simplified and the time needed for this process is reduced from 30 minutes or more to 3-4 minutes. The image registration algorithm was found to be accurate to within 0.1 mm with a head and neck phantom. The DRR generation algorithm generates high quality DRRs with a spatial resolution of 0.289x0.289 mm2/pixel. It removes unrelated anatomical structures for a cleaner background in the DRR to help identify the target isocenter more easily and more accurately. The DRR comparison and portal image verification algorithms readily detect misalignments of less than 0.2 mm. Conclusion: Application of the algorithms in determining patient position shift in actual SBRT cases demonstrated that they were accurate, fast, and reliable. They serve as a useful tool for image-guided radiotherapy.

SU-FF-J-100

Mutual Information as a Metric of Multimodality Contrast Agent Efficacy

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Purpose: Mutual information (MI) has been previously employed for image registration. Assuming *a priori* registration, MI becomes an estimator of image similarity. We apply the concept of MI to the analysis of a feature space formed from multimodality signal intensity distributions. We demonstrate the utility of this concept through the development of a reproducible inter-image metric to evaluate the efficacy of a multimodal contrast agent for x-ray computed tomography (CT) and magnetic resonance (MR) imaging. **Method and Materials:** MR and CT scans were acquired of an anesthetized rabbit in the presence of a multimodal contrast agent. MR and CT scans were acquired pre- and post-injection at fixed time intervals. For each time interval, the MR and CT images were registered, the multimodality feature space was formed and the mutual information between MR and CT was computed using in-house software. The resulting MI metric was compared with measurements of signal intensity enhancement in user-defined regions-of-interest within the liver, kidneys and aorta. **Results:** The MI metric correlates with measurements of signal enhancement in MR and CT due to the presence of contrast agent as seen in the liver, kidneys and aorta. Voxels identified as contributing to the increase in MI correspond to areas of visual contrast enhancement observed on MR and CT. **Conclusion:** We have developed an inter-image metric for the characterization and optimization of a multimodal contrast agent. The computation of the MI metric is automated and can be extended to 3D for the assessment of image volumes and allows for the inclusion of other modalities such as positron emission tomography. Future investigations will further the development of MI and multimodality feature space analysis as a tool in radiation therapy applications including image registration, target definition and treatment response monitoring.

SU-FF-J-101

Evaluation of Two Image Registration Systems

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Purpose: We compare the performance of image registration algorithms adopted by BrainSCan and Philips Syntegra and give a general guide when using these systems. **Method and Materials:** BrainLab BrainScan System and Philips Syntegra System apply volume-based automatic rigid image registration algorithms. Philips Syntegra provides Cross Correlation (CC), Local Correlation (LC) and Normalized Mutual Information (NMI) as optimization metrics and BrainScan applies Mutual Information as an optimization metric. These algorithms are compared for: 1) synthesis images, i.e., the images obtained by applying known transformations to a set of original images, 2) phantom images and 3) patient images. **Results:** For synthesis images, sub-voxel accuracy is achieved. The maximum discrepancies between the registration results of translations and rotations and the known values are less than 0.5 mm and 0.5° for all algorithms. For phantom images, manual registration based on external markers is served as a gold standard to compare with the registration results. The discrepancies are at the order of 2 mm and 2°. For patient images, two radiation oncologists manually registered images independently and compared their results with the results by an automatic image registration system. The discrepancies become much larger due to the complexity of patient setups and density distributions. The capture regions and speeds of these algorithms are compared. **Conclusion:** The algorithms themselves can reach the accuracy of sub-millimeter in translation and sub-degree in rotation. But for clinical uses, the accuracy is reduced because of many errors introduced by positioning and patient motion. Preprocess is important to avoid being trapped in a narrow capture region. Final visual assessment is essential to guarantee reasonable and desired results.

SU-FF-J-102

A New Method for Improving PET and CT Registration in the Thorax On PET/CT

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Purpose: We propose a new method of acquiring the CT data to improve the registration of the PET and CT data in imaging the thorax on PET/CT. **Method and Materials:** In a conventional PET/CT acquisition, the CT and PET data are acquired at two different breathing states. There is an inherent mismatch of the PET and CT because the temporal resolutions of the PET and CT are not matched. We have proposed a new method of acquiring the average CT (ACT) data from the 4D-CT imaging to provide the CT data consistent with the PET data on temporal resolution. We have applied this approach to one esophagus and seven lung patients. The helical CT data were taken helically at 120 kV, 300 mA, pitch 1.35:1, 8x2.5 mm collimation, and 0.5 s rotation and the patients were instructed to hold a breath at mid-expiration during the HCT of the thorax. The PET acquisition was 3 mins per bed. The 4D-CT data of the thorax were taken right after the PET/CT study at 120 kV, 50 to150 mA, cine duration of one breathing cycle plus 1 s, 8x2.5 mm collimation, and 0.5 s CT rotation cycle. We compared the registration between the ACT and PET data, and the registration between the HCT and PET data. **Results:** The PET and ACT data were all consistent at all tumor locations. The mismatch between the HCT and PET data were significantly improved on 4 out of the 8 patients with the ACT data over the HCT data.. **Conclusion:** We have proposed the use of the ACT to improve the registration of the PET and CT data, and demonstrated a significant improvement in lesion localization between the PET and ACT data.

SU-FF-J-103

A Robust Marker Registration Algorithm

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Purpose: We present a novel marker registration algorithm for rigid-body transformations that minimizes sum of least squares between two point sets, and requires no user intervention to handle missing markers. **Method and Materials:** The novel registration algorithm computes the sum of squared distances by finding the minimum weighted matching of a dense bipartite graph (DPG). The space of rigid-body transforms (3 translations and 3 rotations) is explored using a branch-and-bound method. The minimum weighted bipartite match is calculated using a modified Dijkstra's algorithm[1]. The branch-and-bound method is an extension to 3D of the

method in [2]. Unlike conventional singular value decomposition (SVD), i) DPG works with point sets with different cardinalities; and ii) no homology or correspondence has to be defined between reference and target point sets. These advantages provide our algorithm with greater robustness for automatic marker detection, and handling missing markers. Though DPG is not limited by number of markers (N), here N=3 to 7 was used to simulate clinical conditions. **Results:** DPG yielded an accuracy of <0.1mm translational and <0.1° rotational errors, which are within the precision of back projection errors. It was validated using simulated portal images and a high precision table. It was tested on clinical portal imaging data to validate robustness for missing markers. **Conclusion:** DPG provides an accurate and robust point based registration that works with missing markers and different cardinalities, which can be used in conjunction with automatic marker detection.

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SU-FF-J-104

In Vitro Model to Study the Biological Effect of Dose Gradients On a Cell Culture System

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Purpose: Coupled with improved accuracy of radiation therapy delivery, margins around tumour volumes tend to be much tighter. Radiobiological assessment of the changes in cell death at boundaries between the high and low dose regions would improve our knowledge on what is an adequate treatment margin. We have developed a new method of cellular analysis to assess the spatial response of cells across a gradient radiation dose. **Method and Materials:** A549 non-small cell lung cancer cell line was used in a 6 well plate format. The cells were bedded down and maintained at a constant position in the well over the time frame of analysis. Wells 1 and 4 were the unirradiated control wells, wells 2 and 5 were half irradiated and wells 3 and 6 were fully irradiated. Different radiation doses were delivered to the cells in various phases of growth and cell density. The cells were left for various times after irradiation before analysis. The cells were washed with the protein specific Crystal Violet stain and then scanned at 570nM to obtain the protein levels in the well. **Results:** Crystal Violet cell viability correlated with the MTT cell viability assay. An exponential decrease in cell viability was observed when increasing the dose up to 15Gy. The intensity of Crystal Violet stain across the half-irradiated wells showed a sigmoid shape at the interface with close correlation between the slope of the stain and the radiation dose. **Conclusion:** This method provides valuable biological information on the effects of the radiation dose at the beam edge. The results indicate that there may be inter-cellular communication across the gradient dose interface. This may need to be considered when defining the tumour region.

SU-FF-J-105

Tools for Voxel-By-Voxel Correlation of Radiotherapy Dose and MR Signals From Multiple Physiological/functional MRI Modalities

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Purpose: The use of multiple physiological/functional MR modalities for radiation therapy is limited by the lack of tools to correlate voxel-by-voxel MR signal with voxel-by-voxel dosimetric data. Developing such tools is the purpose of this work. **Method and Materials:** We have developed a process and tools that enable the analysis of the data from multiple forms of MR based biological/functional imaging modalities along with the 3D dose distributions from a commercial radiation treatment planning system. Different types of images (CT and multiple MRs) are registered through commercial software (XIO CMS). A 4x4 registration matrix for the rotation and translation of coordinates is extracted from this software and used by our code written in MATLAB for interpolation of data from one coordinate system to another. The computational environment for radiotherapy research (CERR) served as the main platform for handling and visualization of data. We made additions and modifications to CERR to accomplish multiple secondary image –dose display and extraction of voxel-by-voxel registered information. This overall system of tools also has the capability of volumetric dose analysis, such as DVHs, and a voxel-based biological quantify, VED (Voxel uniform dose, similar to EUD except it is calculated in a voxel) can be obtained. **Results:** The tools are being used in our institution in retrospective voxel-by-voxel analyses of radiation responses using various MR modalities, including relative cerebral blood volume (rCBV), Chemical shift imaging (CSI) and Diffusion Tensor Imaging (DTI). **Conclusion:** In order to integrate multiple functional MR modalities into radiation therapy process (planning and outcome assessment), a necessary step is to understand the relationship between MR data and treatment responses. This requires voxel-by-voxel registration between multiple image datasets and voxel-by-voxel correlation between image data with radiation dose. The tools developed in this work serve this purpose.

SU-FF-J-106

FMISO-PET Hypoxia Imaging: A Novel Method to Plan IMRT-Based Boost Radiation to Hypoxic Subvolumes

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Purpose: To investigate the use of [F-18] fluoromisonidazole (FMISO) PET and intensity modulated radiation treatment (IMRT) planning to escalate the dose to hypoxic subvolumes in patients with advanced head and neck tumors. **Method and Materials:** Seventy-three patients with head and neck cancer underwent FMISO-PET scans, with fifty-three of them also undergoing FDG-PET scans as part of ongoing research studies. An initial treatment plan used a PTV defined with a 0.5-cm margin around physician-defined primary GTVs and affected nodal systems. The prescription dose is 70 Gy to the PTV and 50 Gy to the affected nodes, while sparing the spinal cord, mandible, and parotid glands. Physician-defined regions of enhanced FMISO signal were used to define boost volumes on coregistered FMISO-PET/CT images. The boost plan prescription dose to the hypoxic subvolumes is an additional 10 Gy. **Results:** Initial results from example treatment plans for two head and neck cancer patients are as follows (average over patients): to the PTV V_{100} = 87.2%, D_{min} = 6081 cGy, D_{10} = 7303 cGy and to the nodal system V_{100} = 95.9%, D_{min} = 4764 cGy, D_{10} = 5280 cGy. The IMRT boost plan yields V_{100} = 95.1%, D_{min} = 979 cGy, D_{10} = 1012 cGy to the hypoxic PTV. The critical structures of interest received the following dose distributions from the composite IMRT plans: cord D_1 = 3890 cGy, left (contralateral) parotid gland D_1 = 1965 cGy, right parotid gland D_1 = 4907 cGy (same side as primary tumor), and mandible D_5 = 6220 cGy. **Conclusion:** We demonstrate the feasibility of directing dose-escalated IMRT to hypoxic subvolumes in head and neck cancer using coregistered FMISO-PET and CT images. Ongoing research and patient studies are expected to provide conclusive information on the clinical role of this procedure.

SU-FF-J-107

Tumor-Delineation Uncertainties in FDG-PET and FMISO-PET Images and the Effect On Radiation Therapy Plans

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Purpose: To quantify the uncertainties in tumor boundary delineation in head and neck and lung cancer patients using FDG-PET and FMISO-PET images and evaluate the dosimetric impact on radiotherapy plans. **Method and Materials:** We contoured FDG-PET and FMISO-PET based tumor volumes using images from the GE Advance PET scanner. We use the autocontour function of the ADAC/Pinnacle radiation planning system to delineate tumor boundaries at successively higher PET signal levels. CT-based tumor volumes are also contoured by a physician on coregistered PET/CT images. We generated intensity-modulated radiotherapy (IMRT) plans for head and neck patients treating 66 Gy to CT-based gross disease and 54 Gy to nodal regions at risk, followed by a boost to the PET-based tumor. **Results:** The volumes of PET-based tumors are a sensitive function of threshold intensity level for all patients. For FDG-based volumes, a 10% decrease in threshold translates into an approximately 200% increase in volume. Lesions smaller than approximately 8 cm^3 display a more pronounced threshold-volume dependence. The threshold-volume dependence in FMISO scans is significantly more sensitive than in FDG scans. Lung cancer patients show a similar trend to head and neck patients

with a possible overall shift in sensitivity. IMRT planning results on head and neck patients show that the boost dose limit of FDG-based volumes depends on the threshold level chosen for contouring. In one patient the D95 of the planning target volume decreased from 7770 cGy to 7230 cGy when the contour level changed from 42% to 55%. **Conclusion:** PET-based tumor volumes are strongly affected by the choice of threshold level which has a direct dosimetric impact. Further validation and refinement of delineation methods, including a determination of the proper threshold level, should reduce PET-related delineation uncertainties for radiotherapy applications.

SU-FF-J-108

A Non-Invasive Respiratory Motion Compensation System for Predicting Organ Motion in Respiratory-Gated Radiotherapy of the Chest

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Purpose: Non-invasive respiratory gated radiotherapy systems, like those based on external anatomic motion, give better comfort to patients than invasive system during treatment. But to treat efficiently, such systems need a higher correlation between the motion of the external and internal anatomy. So we developed the system to track the motion and compensate for the correlation between internal and external anatomy to accurately predict the dynamic position of internal structures such as the diaphragm and tumor. **Method and Materials:** The respiratory motion compensation apparatus consists of two image boards, a camera and a fluoroscopy system. The camera and one of the image boards captures the abdominal motion of the patient, while the other image board captures the motion of internal anatomy through the fluoroscopy system. Software interfaced to the camera and fluoroscopy tracks the internal anatomy targets and abdominal surface motion induced by respiration simultaneously, using only image processing without any additional physical markers. The fluoroscopic movie was analyzed to obtain the correlation of internal and external anatomy motion in different parts of the diaphragm, abdominal surface and tumor where possible. Using this correlation coefficient, motion of the internal structures in later sessions was predicted based on the same point of abdominal surface motion. **Results:** The range of standard deviations between the predicted positions and the observed positions of some sample structures in each patient was measured about in phase and out of phase respectively. The difference between the predicted and observed positions of the abdominal surface, diaphragm or tumor was reduced a maximum 10 mms under the out of phase to 2mms under the in phase. **Conclusion:** This non-invasive respiratory motion compensation system accurately predicts the respiratory motion of internal structures within 2 mms. Thus, this may improve the accuracy of gated or conventional 3D conformal radiotherapy.

SU-FF-J-109

Analysis of the Organ Motion Effects On the Fluences for Liver IMRT

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Purpose: To study the effects of organ motions due to respiration on the fluences of IMRT plans and to develop an acceptable limit of organ motion for gated IMRT with DMLC delivery. **Method and Materials:** The fluence changes due to organ motion were calculated using Chui's algorithm. We limited our studies on the fluence changes from superior-inferior organ motion perpendicular to the motion of MLC. 108 fluence maps of 16 IMRT plans for 8 liver patients were calculated, analyzed, and compared without and with gating. The motion effects on the fluence maps were evaluated by both the fluence differences and the χ function which is a revision of the γ function. The max. displacements of the organ motions of all of these cases were analyzed and correlated with the change of fluences for liver IMRT plans. **Results:** The effective fluence due to organ motion of one of the patients was incorporated in dose plan for illustration. The DVH showed that 5 mm of motion displacement with gating seemed to have a little effect on the PTV and normal liver coverage while 9 mm without gating caused 8% drop in D90 and 3% increase in V30 of normal liver. Furthermore, four test cases with various fluence maps were subject to simulated motion with max. displacement ranging from 5 to 25 mm. To keep the $|\chi|$ value >1 percentage for fluence safely below 25% or the percentage of DD>3% below 40% with or without gating, 8 mm max. displacement seems to be a good cutoff. **Conclusion:** After 108 fluence maps of 8 patients and four test cases of different fluence patterns were analyzed, it is concluded that an 8 mm maximum motion displacement seems to be a practical and acceptable standard with gating technique.

SU-FF-J-110

Comparison Between Free Breathing, Slow and Respiratory Correlated CT in Radiation Treatment Planning for Lung Cancer Patients

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Purpose: Radiotherapy for lung cancer requires a margin for internal movement of the tumor. Reduction of this margin and thus dose escalation may be possible by using a slow or a respiratory correlated CT (RC-CT) during radiation treatment planning. In this study these two novel methods are compared to the use of a conventional free breathing CT (FB-CT). **Method and Materials:** On a modified Siemens Sensation 10 an FB-CT and an RC-CT scan were acquired in nine patients. The RC-CT scan was used to measure tumor motion and to reconstruct a CT at 10 respiratory phases (10p-CT). One of these was termed the mid-ventilation CT (MV-CT) and by averaging all CTs, a slow-CT could be reconstructed. Four treatments were planned based on the FB-CT (with conventional internal margin); the slow CT; the 10p-CT, and the MV-CT (with an internal margin of (motion amplitude)/4). Mean tumor dose was calculated for these four plans for a fixed mean lung dose of 15Gy. The possibility of coldspots (<95%) was investigated by determining minimum tumor dose that occurred during respiration. **Results:** The mean tumor dose in the FB-CT based plan was 74Gy, for the MV-CT 100Gy, for the 10p-CT 95Gy, and for the slow-CT 101Gy ($p=0.0001$ for FB-CT vs. other; $p=0.12$ for MV-CT vs. 10p-CT). Coldspots occurred occurred in the patient with the largest tumor motion (15mm amplitude) in the case of a plan based on a slow-CT scan. **Conclusion:** Since radiation treatment planning based on a slow-CT can lead to underdosage in tumors moving with a large amplitude and the delineation of the 10p-CT is rather cumbersome, we conclude that using an RC-CT scan to reconstruct a mid-ventilation CT and applying a margin of one quarter the tumor motion amplitude, is the most suitable method for radiation treatment planning in lung cancer patients.

SU-FF-J-111

Correlation of Target Movement, Diaphragm Motion and External Sensor Signals for Respiratory-Gated Hepatoma Radiotherapy Using TACE as a Target Indicator

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Purpose: To assess the correlation among target movement, diaphragm motion and external sensor signals to predict the internal safe margin required for respiratory-gated radiotherapy for hepatoma patients. Impact of gating window size on internal safe margin selection was also evaluated. **Method and Materials:** 5 hepatoma patients who previously received trans-arterial chemoembolization (TACE) treatments were enrolled in this study. The patients were imaged fluoroscopically for 60 seconds to record the internal motion patterns of the diaphragm and of the TACE through an image-capture device. The skin motion pattern was obtained by an in-house developed sensor. Locations of the diaphragm and the TACE on the fluoroscopic images were identified manually frame-by-frame. Means and standard deviations of the differences between the displacements of the sensor signal and the diaphragm (SD), of the sensor signal and the TACE (TS) and of the diaphragm and the TACE (TD) were calculated for various gating window settings. Internal safe margins as defined by mean±1.5*standard deviation were calculated. **Results:** Displacement differences of patient #1-5 for 50% gating window size were determined to be 1.3±1.3, 1.2±1.1, 2.9±2.1, 3.0±1.9 and 2.4±1.7 mm for SD; 2.2±1.5, 1.1±0.7, 1.3±1.1, 4.8±1.5 and 2.1±1.5 mm for TS; and 0.8±0.4, 1.4±0.2, 1.2±0.1, 2.9±1.0 and 1.1±0.2 mm for TD. The results also showed that selection of different gating window sizes had limited effect on the size of the internal safe margin. **Conclusion:** Inconsistent motion patterns among target, diaphragm and external skin sensor must be taken into consideration when determining internal safe margin for hepatoma patients.

SU-FF-J-112

Design and Applications of a 4D Simulator for Respiratory Motion

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Purpose: To design, construct, and evaluate a pneumatic respiratory-motion simulator for 4D radiotherapy. The device should be able to operate in dynamic mode for real-time simulation of patient breathing motion as well as snapshot mode for static dose measurement. **Method and Materials:** A simulator incorporating a cylindrical air reservoir with a piston was constructed as a tool in 4D radiotherapy studies. The piston movement is controlled by a programmable logic controller (PLC) which is interfaced to custom software written in Visual Basic (VB). The air reservoir is connected to a lung phantom made of two pulmonary simulation balloons. The pressure inside the lung phantom is monitored by a detector whose input is feedback to the PLC. The lung phantom is immersed in a water-filled box to simulate the normal tissue surrounding actual human lungs. The box is connected to a water reservoir to allow breathing of the lung phantom. A rubber ball is attached to the inner side of the phantom to simulate a lung tumor and gold seeds are implanted into it for seed-tracking studies. Spirometer-based patient respiratory waveform data in ASCII format were obtained from our department's breath-hold clinical study. The waveform data are input to the VB program and sent to the simulator for controlling the simulation. **Results:** Preliminary evaluation of the simulator using several patient waveforms has been conducted. The respiratory motion of the lung phantom is found to be reproducible. **Conclusion:** A prototype respiratory-motion simulator has been built which should prove valuable for 4D radiotherapy and related studies (gating, respiratory-induced organ deformation). Its unique design of using pneumatic means to simulate breathing motion allows more realistic simulation studies including those involving animal lung models.

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SU-FF-J-113

Determination of Appropriate Lung Volume for Dosimetric Planning and Analysis From 4D CT

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Purpose: Lung volumes at different breathing phases are substantially different from each other based on 4D CT. They are also different from the lung volume based on conventional 3D ungated CT. However, the dosimetric criteria and lung toxicity data used in the current planning process are based on the conventional 3D CT lung volume. Determining appropriate lung volume from 4D CT for treatment planning of lung cancer is the purpose of this work. **Method and Materials:** We obtained 4D CT scans of 10 patients using a GE LightSpeed RT scanner in combination with the Varian RPM respiratory gating system. For two of these patients, we have also obtained conventional 3D CT scans. The 4D CT scans were reconstructed into 10 breathing phases, as well as maximum, minimum, and average intensity projections. The lungs were then contoured for each phase and intensity projection, as well as for the 3D scans, and volumes for these contours were obtained. **Results:** We find that the average intensity projection (AveIP) is the most consistently close to the 3D CT volume, differing at most by about 3% of the total lung volume. The phase volume most closely approximated by the AveIP is the 20% phase (mid-exhalation) or the 80% phase (mid-inhalation), differing from the AveIP on average by 1.8±2.2% and -1.2±1.7%, respectively. The lung volume from the maximum intensity projection (MIP) is on average less than the AveIP volume by 11.4±2.3%. **Conclusion:** The lung volume from the 20% or 80% phases or the AveIP based on 4D CT should be used in the treatment planning for lung cancer. While the MIP is useful for ITV determination, it underestimates the lung volume compared to the conventional 3D CT.

SU-FF-J-114

Dose Escalation Resulting From Reduced Margins Used to Generate the Planning Target Volume

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Purpose: Decreasing margins that account for setup uncertainty and respiratory-induced tumor motion can potentially result in improved treatment of lung cancer. The present work was designed to examine the dosimetric impact of reducing the margins used to generate the planning target volume (PTV). **Method and Materials:** Eighteen patients treated for non-small cell lung cancer were selected. Treatment plans were generated based on two sets of CTVs. One obtained while free-breathing explicitly accounted for respiratory-induced tumor motion, while the other acquired at end-expiration or inspiration simulated treatment under breath-hold. Margins used to generate the PTV were uniformly reduced in 2-mm increments from the clinically used 7-mm margins while escalating dose to the CTV. In the first part of the study, the dose to the CTV was escalated as long as normal tissue toxicity levels did not exceed that of the treatment plan actually used. In the second part, dose to the CTV was escalated until structures received the maximum dose-volume constraints allowed in our clinic. **Results:** Preliminary results showed that reducing the margin used to expand the breath-hold CTV from 7 to 3-mm allowed an increase of slightly higher than 10% of the prescription dose to be delivered to the tumor without exceeding normal tissue toxicity levels. When explicitly accounting for respiratory motion, a 1-mm margin was needed to observe statistically significant increases in dose to the CTV. By increasing the dose until critical structures received the maximum permissible dose, dose escalation of over 25% was observed using a 5-mm margin to generate the CTV. Statistically significant increases in dose were only slightly higher using a 3-mm uniform CTV expansion to generate the PTV. **Conclusion:** As a result of this study, we have observed that increased doses can be delivered to the tumor by reducing margins used to generate the PTV.

SU-FF-J-115

Effects of Anatomical Changes Due to Response to IMRT On Radiation Doses to Organs at Risk; A Case Study for Image Guided Adaptive IMRT

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Purpose: The purpose of this study is to evaluate dose volume histograms of the PTV, and the organs at risk (OAR) during a course of IMRT treatment of a patient with olfactory neuroblastoma. The study will help simulate adaptive IMRT for patients with similar disease. **Method and Materials**: A 46 years old male patient with unresectable right-sided olfactory neuroblastoma with right eye proptosis of about 1.5cm was treated with IMRT using a Brainlab Novalis SRS system. The daily dose was 180cGy to the isocenter for 35 fractions. The initial PTV volume measured to be 108cc. A Brainlab mask system with a daily positional accuracy of 1mm was used to immobilize the patient. The eyes, optic nerves, and chiasm were defined as organs at risk. 8 step and shoot IMRT beams were defined. The CT images of the patient acquired initially, and at fraction 34 were fused, and compared. **Results:** The gross tumor volume (GTV) decreased during the course of IMRT from 108cc to 38 cc, a 65% reduction in volume. The right eye moved back to its position by 9mm during the IMRT course of treatment, a linear transition of 0.3mm/FX. The maximum dose to the right orbit increased from initial dose of 90cGy/FX to 180cGy/FX at the last fraction. The original planned OAR dose was significantly increased to both the right orbit, as well as the right optic nerve due to tumor shrinkage compared with the start of the treatment. **Conclusion:** In the absence of image guided adaptive therapy for tumors, which respond rapidly to radiotherapy, more conservative dose limitations may be necessary for the organs at risk. In addition, imaging studies during the course of the treatment would help evaluate, and possibly modify the IMRT plan.

SU-FF-J-116

Image-Guided Adaptive Radiation Therapy for Improving Level I Lymph Node Coverage for Head and Neck Cases

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Purpose: Correcting anterior-posterior, lateral, superior-inferior, pitch, roll, and yaw with Image-Guided Radiation Therapy (IGRT) will not completely correct for anatomical deformation. The purpose of this work was to identify anatomical deformation error and develop multiple strategies for addressing this error using adaptive IGRT. **Method and Materials:** Ten H&N patients have been treated with helical tomotherapy. Megavoltage CT (MVCT) images were acquired prior to treatment The daily setup were then used to calculate the random positional setup errors

between the setup marks on the patient's mask and the internal anatomy. Level I lymph nodes (LV1) and the cord were contoured on each MVCT image. DVHs and LV1 EUDs were then calculated for each fraction. If the 2 Gy per fraction isodose line did not cover the LV1 nodes, then the treatment delivery was re-planned and adapted to account for anatomical deformation. **Results:** The total shifts were measured for over 400 treatment fractions. The standard deviation was ±2.8 mm in the AP direction, ±2.9 mm in the lateral direction, and ±3.2 mm in SI direction. Dose reconstruction results indicated that the LV 1 nodes were frequently being under-dosed (*even with IGRT*). Using IGRT to align the patient relative to the spinal cord resulted in a reduction in the LV1 nodal EUD by 2 to 6 Gy. This is of particular concern because the risk (5 to 50 percent) of LV1 involvement for node-positive patients. By utilizing adaptive therapy, the LV1 were completely covered by the prescribed dose (*50 Gy*) in all cases. In addition, dose to the cord and mandibles were minimized. **Conclusion:** Adapting the treatment delivery by modifying the anterior border of the field can correct for the decrease in coverage due to anatomical deformation. This technique is an alternative to increasing PTV margins that allows increased sparing of normal tissues.

SU-FF-J-117

Inter and Intra-Fractional Patient Motion for a Set of Immobilization Devices

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Purpose: We assessed the magnitude of inter- and intra-fractional patient motion for a broad set of immobilization devices. **Method and Materials:** In our practice for proton radiotherapy, we verify patient setup prior to each treatment field by means of digital imaging. Deviations from the "expected" patient position (with 6 degrees of freedom on our patient positioner) are stored in a database and were retrospectively analyzed for patient setup accuracy. Data was analyzed for each ordinal direction and for the combined spatial displacement. Immobilization devices were separated into "rigid" and "non-rigid" devices depending on their connection to the patient positioner. **Results:** Systematic offsets in intra-fractional motion are small for all immobilization devices, and less than 0.2mm for translations and less than 0.1 degrees for any rotational axis. Although the mean translation per ordinal direction is often smaller than 1mm, the mean spatial displacement for intra-fractional motion for rigid devices is 1.3mm compared to 1.9mm for non-rigid devices. The modified Gill-Thomas-Cosman frame controlled intra-fractional patient motion best, with a 95% probability (v95) of observing less than 1.8mm of motion. For the widely used IC-mask, the v95 value is below 3mm. All other immobilization devices have a v95 greater than 3.0mm for intra-fractional patient motion, while the mean spatial inter-fractional displacement (rigid devices only) was at least 3mm with a v95 of at least 6mm. **Conclusion:** Intra-fractional patient motion is generally smaller than inter-fractional patient motion, which indicates that immobilization devices are better at maintaining a certain patient position than at reproducing this position between fractions. Immobilization devices that rigidly connect to the patient positioner ensure better immobility than those that do not. However, none of the immobilization devices achieved sub-millimeter immobility. Patient position verification remains necessary to achieve high setup accuracy.

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SU-FF-J-118

Lung Target Volume Inaccuracies Due to Motion in Non-Gated and Gated CT Images

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Purpose: To quantify lung planning target volume (PTV) inaccuracies due to motion in non-gated and gated CT images. **Method and Materials:** A motorized test object: sphere diameter (2.5, 5.0 cm), orbit diameter (1, 2 cm) and period (3-5 sec.) was constructed. For non-gated helical CT, pitch, slice width, interval and acquisition time was varied. For gated CT, phase and slice acquisition time was varied. Structures were automatically contoured and a 1 cm margin added using a 3D growing tool. A performance metric, normalized volume (NV), was defined as measured PTV divided by theoretical volume (NV=1, static conditions). A uniform margin, based on a spherical model, was calculated over a range of orbital speeds. External marker motion for ten lung cancer patients was measured and minimum residual motion was calculated for a duty cycle spanning CT slice acquisition time. **Results:** Optimal non-gated helical protocols (time: 1.0 sec./rotation, pitch: 0.4-0.7, width: 2-3 mm, interval: 1 mm) achieved NV>0.85 over a range of clinically relevant orbital speeds; a standard protocol for lung (time: 1.5 sec./rotation, pitch: 1.5, width/interval: 3 mm) achieved NV>0.70. Gated protocols (time: 1.0 sec./rotation, width/interval 2-3 mm) achieved NV>0.65 over the same range of orbital speeds. For the lung patients, average orbital speed of the external marker ranged from 0.5 to 1.5 cm/sec. and residual motion ranged from 1.5 to 4.6 mm. Assuming a 1:1 ratio of marker to tumor motion, margins for non-gated CT of 0.7 to 1.5 mm (optimal) and 1.5 to 3 mm (standard) were required to achieve NV=1. For gated CT, margins of 0.3 to 1 mm were required. **Conclusion:** Inaccuracies in PTV delineation due to tumor motion occur in both non-gated and gated CT images. Average orbital speed of an external marker for lung patients may be used to estimate tumor motion margin.

SU-FF-J-119

Margin Calculations for Prostate Radiotherapy Using Electronic Portal Imaging, Implanted Fiducials and Three Localization Methods

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Purpose: To quantify the PTV margin for prostate radiotherapy based on daily electronic portal images (EPIs) of intraprostatic fiducial markers and three localization methods: Skin marks, visual matching and computer aided matching. To correlate with high statistical accuracy the prostate and bony anatomy location based on the EPIs. **Method and Materials:** A cohort of 20 patients, receiving standard course fractionation, had gold fiducial markers placed in their prostates and marker position relative to isocenter was determined based on CT simulation. Skin marks established initial localization. Daily orthogonal pre-treatment EPIs were used to visually identify the markers and determine any 3D offsets. Finally, off-line computer aided localization was performed. 3D localization offsets and margins were determined for each method. Prostate to bony anatomy position correlation was based on an 80 patient cohort and evaluated with Pearson r^2 correlation value ($r^2 > 0.75$ suggests strongly correlated). **Results:** Margins based on localization using skin marks (visual matching) and [computer aided matching] are 5.1 (2.7) [1.5] mm Sup-Inf, 7.3 (2.9) [2.0] mm Ant-Post and 5.0 (2.8) [1.0] mm Right-left. The Pearson r^2 correlation value for the bony anatomy vs. prostate is 0.12 Sup-Inf (not correlated), 0.30 Ant-Post (not correlated), and 0.79 Right-Left (strong correlation). **Conclusion:** There is a substantial reduction in the margin from the skin mark setup to the visually matched localization and further to computer aided localization. A nearly 4 fold decrease from skin mark setup to computer matched localization in the Ant-Post direction indicates a potential for dose reduction of critical structures and increased dose to the PTV. Correlation results suggest that bony anatomy cannot be used as a predictor of prostate motion (except in the Right-Left direction), and if so used, may be harmful. **Conflict of Interest:** Varian Medical Systems partially funded this research.

SU-FF-J-120

Patient Motion During Extracranial Stereotactic Radiosurgery

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Purpose: Advances in image-guided treatments have made frameless stereotactic radiosurgery (SRS) feasible. Extracranial SRS treatments are highly conformal, and technical delivery precision on phantoms has been shown to be less than 1 mm. The human component of error, i.e. voluntary and involuntary motions during the treatment, plays an increasing role in the determination of PTV margins. The residual motion between imaging intervals during image-guided treatments constitutes the treatment uncertainty and needs to be compensated by the application of a PTV margin. **Method and Materials:** During Cyberknife extracranial SRS, the patient position is verified by orthogonal x-ray images every 80 seconds on average. Data of 90 extracranial SRS patients have been analyzed. The extent of patient motion has been studied during the whole treatment, the first 5 minutes and first 15 minutes of each treatment. Motion patterns of anatomical sub-sites were studied. **Results:** The maximum frequency of all translational patient motions was in the range of 0.02-0.2 mm, with 90% of all motions below 1 mm. No differences between the three translational directions have been observed. The maximum frequency of rotational patient motions was between 0.1-0.2 degrees, with a wider distribution in the degree of roll. The average patient motion for cervical spine was 0.47

mm, thoracic spine 0.34 mm, and lumbar spine 0.29 mm. In the 214 fractions analyzed, patients moved on average 1 mm away from their original setup position after 5 minutes of treatment. No statistically significant difference exists for the range of patient motion during the first 5 or 15 minutes as compared to the whole treatment. **Conclusion:** For image-guided treatments, PTV margins of 1.0 mm include 90% of observed patients motions for static lesions. Larger margins may be necessary if the treatment field is not rotationally symmetric around the isocenter.

SU-FF-J-121

Patterns of Intraabdominal Organ Motion as Measured by Quantitative 4D CT

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Purpose: Many clinics are investigating the use of IMRT for intraabdominal malignancies. Respiratory motion must be measured to determine optimal target and normal tissue margins. The purpose of this study was to quantify the movement of abdominal organs with non-coached respiration. **Method and Materials:** Ten patients with hepatobiliary malignancies underwent quantitative spirometry during a multislice-CT following standard helical-CT simulation (Philips Brilliance 16-slice). Abdominal CT images were reconstructed by tidal volume, capturing end-expiration, mid-inspiration, end inspiration, and mid-expiration. Each CT reconstruction was fused with the standard helical-CT simulation. The liver, spleen, stomach, pancreas, kidneys and surgical clips were contoured for each patient when applicable. The organ motion was determined by measuring the distance between the geometric center of end-expiration and end-inspiration contours. Hysteresis was determined by measuring the distance between the geometric centers of the mid-inspiration and mid-expiration contours. **Results:** A total of 72 structures have been contoured in eight patients. Five patients were status-post pancreatic resection. Hysteresis in organ movement was demonstrated when comparing mid-inspiratory and mid-expiratory contours, with differences in mid-inspiration and mid-expiration contours of up to 1.59cm. Total max-inspiratory to max-expiratory movement for the liver, stomach, kidneys, spleen, and pancreas were 1.00, 1.46, 1.29, 1.52, and 1.16cm. Total mid-inspiratory to mid-expiratory movement for the liver, stomach, kidneys, spleen, and pancreas were 0.51, 0.76, 0.71, 0.78, and 1.12cm. The maximal movement for the liver, stomach, kidneys, spleen and pancreas were 1.47, 2.47, 1.90, 2.29 and 1.73cm. Results for the surgical clips were similar. **Conclusion:** Despite the anatomic variation expected in a diverse population, all the upper abdominal organs moved inferiorly and anteriorly with inspiration. Each organ moved at least 1cm on average, and more than 2cm in certain patients. Hysteresis was significant in some patients. Further work to investigate changes in dose distribution from this movement is ongoing.

SU-FF-J-122

Planning Target Volumes for Image-Guided Radiation Therapy of Prostate Cancer

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Purpose: Image-guided radiation therapy has the potential to reduce the uncertainty in targeting the clinical target volume (CTV) for prostate cancer. This allows a reduction in the size of the planning target volume (PTV). Determination of an appropriate PTV is a non-trivial task. Issues that need to be considered include the magnitude of the uncertainties, the shape of the dose distribution, and the desired treatment goal. This work examines the PTV requirements for image-guided radiation therapy of prostate cancer. **Method and Materials:** The effect of geometric uncertainties is modeled to determine appropriate PTV margins. Random uncertainties are modeled as a convolution of the dose distribution, and systematic uncertainties as probability weighted shifts of the dose distribution. PTV margin requirements are examined as a function of the use of image-guided positioning (no correction vs. on-line correction), treatment technique (conformal vs. intensity modulated radiation therapy), and probability of achieving 95% minimum dose to the CTV (95% vs. 99%). **Results:** For a 95% probability of achieving the treatment goal, PTV margins of 6-7 mm are required if no correction is performed. The use of on-line position correction reduces the required margin to 1-2 mm. Achieving the treatment goal with 99% probability requires >10 mm margins with no corrections, while 2 mm margins are sufficient with on-line corrections. The use of conformal vs. IMRT techniques has minimal impact on the required PTV. **Conclusion:** The results suggest image-guided on-line positioning correction allows substantial reduction of PTV margins. Achieving specific treatment goals with a very high level of confidence may be impossible without on-line corrections. Since patient positioning and internal organ motion may no longer be the dominant sources of uncertainty when on-line corrections are performed, these results should be interpreted cautiously until factors such as intrafraction motion are incorporated into the analysis.

SU-FF-J-123

Residual Tumor Motion in Respiratory Gated CT Treatment Planing

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Purpose: Respiratory gated CT planning and treatment has been used to reduce widened margins that accounts for motion-induced uncertainties. This study evaluates the residual tumor motion within the gating window of gated CT scans and associated margin. **Method and Materials:** Gated CT data were acquired in 24 patients (23 lung cancer, 1 liver cancer) at the end-of-expiration and at the end-of-inspiration on a PQ5000 CT simulator with a commercial gating system. Three moving spherical phantoms were also used to simulate tumor motions at 2-4 sec/cycle. Gated CT data at the end-of-expiration was used for treatment planning for gated intensity modulated radiotherapy (IMRT) or three-dimensional conformal radiotherapy (3DCRT). Residual target motion within the gating window was determined using target motion determined from the CT pairs, recorded surrogate marker motion at the end-of-expiration and end-of-inspiration. **Results:** Phantom study suggests that breathing cycle should be > 2 sec/cycle to avoid image artifacts induced by residual motion. A minimum 3 sec/cycle breathing period is required for patients undergoing gated CT in our institution. In the patient study, most tumors moved in the superior-inferior direction ranging from 3mm to 17mm. The residual target motion within the gating window ranged 0.6mm to 3.4mm. Based on a mean positioning error of 3.0 mm for gated treatment reported in the literature, a margin of 6.0mm to 9.0mm (within 2σ of independent Gaussian distributions) was required to account for both daily positioning error and residual tumor motion in gated IMRT and 3DCRT, corresponding to an additional margin of 0.1 mm to 3.1 mm comparing to that without accounting for residual tumor motion. **Conclusion:** Residual tumor motion within the gating window should not be ignored. Additional margin accounting for residual can be estimated from gated CT data and applied to gated treatment.

SU-FF-J-124

The Unappreciated Benefits of Randomness and Slow Delivery with Organ Motion

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Purpose: Expand a groundbreaking study (C. Yu, et al., PMB 43, 91) to explore the implications for helical tomotherapy and to expand it with more exploration of random components of the organ motion function. **Method and Materials:** Three MatLab codes were independently constructed to simulate sinusoidal motion (amplidute, scan speed, and frequency varied) superimposed upon a constant scan speed as in C. Yu, et al., PMB 43, 91. The fluence at a point in the moving target (tumor) is calculated by the amount of time that point spend in the beam (1 cm wide) assuming a constant fluence rate. These codes with varying resolutions and frames of reference are cross-checked. A resolution of 0.01 cm and 0.005 sec were found to be sufficient. **Results:** Motion plots of points in the target are compared to the fluence profiles for a variety of parameters. Hot and cold spots in the target (dose modulations) are small for typical helical tomotherapy couch speeds with longitudinal target organ motion. The edge is blurred because the points move in and out of the beam at both sides. When cycle-to-cycle randomness is added to amplitude and frequency, these modulations are high sensitivity to these parameters. However, with multiple fractions at random phases, the modulations decrease quickly and single fraction variability is quickly averaged out. **Conclusion:** Typically used helical tomotherapy couch speeds imply less concern for dose modulations from longitudinal tumor motion. There is still a need for a

large enough PTV for edge blurring. Multiple fractions smooth out modulations that occur in a single fraction from randomly phased motion. Methods that remove this randomness may not benefit from this averaging process.

SU-FF-J-125

Thoracic Organ Motion as Assessed by 4D CT: Prone Versus Supine

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Purpose: Radiotherapy is sometimes carried out with the patient in prone position. The purpose of this work is to study the changes of respiratory organ motion for patients in prone versus in supine position. **Method and Materials:** We obtained 4D CT datasets for 15 patients, 5 in prone and 10 in supine position, using a GE LightSpeed 4D CT scanner. Patients in both positions were immobilized by Alpha cradle. Lung movement (the change in lung spatial dimensions between maximum and minimum inspiration) in the superior-inferior (S/I) direction was measured on the 4D CT, as well as in the anterior-posterior (A/P) and left-right (L/R) directions in two transverse CT images near the diaphragm and near T4. We also measured the movement of the anterior chest wall with respect to the table top on the T4 transverse CT image as well as on the transverse image defined by the nipple. **Results:** Average lung movement changes from supine to prone position were: in 17.8 to 11.5 mm in S/I direction changes, and 1.6 to 0.5 mm in the A/P direction on the T4 image. In the transverse image defined by the nipple, we observed chest wall average movement of 0.1±0.4 mm in prone position versus 1.9±0.4 mm in supine position. Similarly, at the level of T4, the chest wall moved 0.3±0.3 mm in prone setup and 2.0±0.7 mm in supine position. **Conclusion:** Respiratory organ motions in thorax are generally reduced when patient position is changed from supine to prone. We have found a significant reduction in anterior chest wall movement for the prone position, an advantage of treating breast cancer in the prone position.

General Poster Discussion
Exhibit Hall 4A
Therapy

SU-FF-T-01

A Newly Designed LDR Brachytherapy Applicator for Treatment of Cervical Cancer with Extension Into the Lower Vagina

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Purpose: The new applicator was designed at the University of Kentucky for treatment of cervical cancer with the extension into the vaginal. The design incorporates properties of both the Fletcher-Suit applicator and vaginal cylinder. A dosimetric evaluation of this applicator was performed using TLD measurements and the results were compared to the presently available Fletcher-suit applicator and a commercially available treatment planning system. **Method and Materials:** Presently, patients with cervical cancer extending to the lower vaginal are being treated with the standard Fletcher suit applicator followed by treatment with a vaginal cylinder. To eliminate the possibility of overdose to critical organs such as of bladder and rectum, arising from two separate treatments, and also reduce the patient inconvenience a new applicator was designed to combine these treatments. To evaluate the dosimetric characteristics of this applicator, a solid water phantom was constructed to accommodate both the applicator and LiF TLD chips. The positions of the TLD chips were selected to represent the most commonly calculated points including vaginal mucosa and point A, as defined in ICRU report 38. The applicator was then loaded with Cs-137 sources, using the standard loading scheme. The 1 cm^3 TLD chips were placed in the phantom along with the applicator. The experimental results were compared with the calculated values using a treatment planning system. **Results:** The data compared dose rates at different points in the phantom which represent points along vaginal mucosa with analogous points from the same digitized set-up in the treatment planning system. The agreement was within or close to 10% for most points. Also, dose rates from the new applicator compared well with the Fletcher-Suit applicator. **Conclusion:** This dosimetric evaluation provides solid evidence that this applicator is a safe and effective LDR device to treat cervical cancer with extension into the lower vagina.

SU-FF-T-02

Comparison of a 3D Multi-Group Sn Particle Transport Code with Monte Carlo for Intracavitary Brachytherapy of the Cervix Uteri

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Purpose: To calculate and compare 3-D CT-based patient dose distributions between Monte Carlo and a 3D multi-group S_n particle transport code for intracavitary brachytherapy of the cervix uteri. **Method and Materials:** MCNPX version 2.5.c, a general purpose Monte Carlo code, was used to simulate the tandem and ovoids. An input file was created that simulated the tandem and ovoids together. A reference geometry was created in the input file whereby each applicator could be positioned in each patient CT derived geometry by applying a transformation obtained from the patient CT scan.

A 3D multi-group S_n particle transport code, Attila™ (Transpire, Inc., Gig Harbor, WA) was used to simulate the same applicator set. Each applicator was built in Solidworks™(Solidworks Corp., Concord, MA), a mechanical design package and then assembled with a coordinate transformation and rotation for each patient case. Solidworks™ exported applicator geometries as a parasolid geometry, which were imported into Attila™ for calculation.

Water photon kerma rates were converted to dose delivered over the length of one insertion. Dose matrices were overlaid on each patient geometry. Dose volume histograms and point doses were compared for two patient cases. Applicator to applicator comparisons were performed between the two codes. **Results:** The Attila™ code calculated doses to within ±4% of MCNPX for 95% of the points in a comparison of the ovoid and to within ±4% of MCNPX for 94% of the points in a comparison of the tandem. On average, Attila™ calculated dose fourteen times as fast as MCNPX. **Conclusion:** The Attila™ code can calculate doses for the tandem and ovoids accurately and with less computational time than MCNPX. Further refinements may decrease calculation times for the Attila™ code. **Conflict of Interest:** This research was supported in part by a sponsored research agreement with Transpire, Inc., Gig Harbor, WA.

SU-FF-T-03

Design and Quantitative Analysis of a Novel Brachytherapy Robot

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Purpose: To design a novel brachytherapy robot and compare its static manipulability characteristics to two well-known robotic manipulators: the Puma560 and the Stanford Arm. **Method and Materials:** The open-source 3-D Slicer program was used to model the prostate from clinical CT data. Workspace dimensions were determined and applied to the design of a new robot. The robot was modeled mathematically using the modified Denavit and Hartenberg representation of robotic manipulators. The static force and velocity manipulability ellipsoids were calculated for all three robots in several different poses using the Robot Toolbox for Matlab® (P.I. Corke, CSIRO, Australia, 2002). The force and velocity transformation ratios were computed and compared for similar poses. A small transformation ratio indicates the robot is sensitive to errors in control tasks, but not well-suited for actuation tasks. The manipulability measure was also calculated. The manipulability measure is a quantitation of the range-of-motion of a robot in a given pose. **Results:** The calculations show the brachytherapy robot can implant a needle with a good balance of force and velocity with a high percentage of the maximum values. The Puma560 is relatively balanced, however most transformation ratios are less than 10% of the maximum. The Stanford Arm is not well balanced in both configurations studied. The Stanford Arm's transformation ratios are also relatively low percentages of the maximum. The manipulability measures for the brachytherapy robot were between 1.6 and 5 times higher than the other robots. **Conclusion:** Several robots have been developed for brachytherapy implantations. None have provided quantitative comparisons to other robots. Here, static manipulability calculations compare different robots with a specific pose (initial task-oriented configuration). Our brachytherapy robot has balanced transformation ratios and also shows a high degree of manipulability. Initial calculations show that this robot is well configured for needle insertion tasks.

SU-FF-T-04

Experimental Method Development for Direct Dosimetry of Permanent Prostate Brachytherapy Implants

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Purpose: To ascertain if PET DICOM data can be used for the quantitative description of dose distribution in support of direct prostate seed dosimetry. **Method and Materials:** Simulated brachytherapy seeds were constructed containing trace amounts of a positron emitter F-18, such that all annihilation events took place in the encapsulation wall. An acrylic prostate phantom containing these seeds was imaged with a GE Discovery PET/CT scanner. The PET scan data was used as source in the input for Monte Carlo calculation of dose distribution due to the F-18. This dose distribution was then compared to computations wherein the source was restricted to the encapsulation wall. This was done to determine if the measured data could be used to accurately compute the annihilation dose, which in turn could be used to compute the therapeutic dose due to known seed activity. **Results:** Examination of the dose distributions indicates a close agreement between the measured data and theoretical computational experiments for certain cases. We found that 2D acquisition with default reconstruction resulted in a maximum difference in transaxial dose distribution of 15% in a single voxel and a mean difference of 4% for the remaining voxels. The mean discrepancy between the ideal and PET based computations are within or close to calculation error of 2% to 4%. These results do not reflect any optimized acquisition protocol that can further reduce the observed differences. **Conclusion:** This work indicates there is potential for using PET data for the proposed link between the therapeutic brachytherapy dose and the dose due to a trace amount of encapsulated positron emitter developed by Sajo and Williams. Without needing seed location information, clinical implementation of this method could significantly reduce the time needed for post-implant evaluation, and several of the uncertainties and limitations inherent in current prostate brachytherapy dosimetry.

SU-FF-T-05

Interactive CT Based Seed Visualization, Localization and Verification in 3D

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Purpose: This work is to introduce an intuitive tool utilizing a home-made user-interactive 3D visualization interface for prostate seeds verification after automatic and manual seed searching. **Method and Materials**: This home-made program is written In C++ and QT (Trolltech, Inc) and VTK library (Kitware, Inc) for both Windows and Linux. CT raw data was reconstructed with a slice thickness of 0.7mm to reduce under sampling problem. First threshold with user chosen value, then iso-surfaces were rendered with a user-chosen color for easy visualization. An automatic method will localize the well-separated seeds whose volume is within 0.5-1.5 times of actual seed size. Then manual pick up could select the overlapped seeds by just one mouse click. All distances between the newly selected seed to already selected seed coordinates are calculated. If less than 1mm, the seed will be discarded. The seed orientation is defined as the orientation of the longest axis of the volume bounding box. The seed coordinates and orientations can be exported as an ASCII file. **Results:** A phantom with dummy seeds in different orientation and regular spacing and a clinical prostate CT data set were used for testing. The standard deviation for positioning is 0.29mm, 0.34mm in plane and 0.19mm in axial direction. Clinical patient CT data is used to test the seed localization program, the fake seed like bone or calcification can be deleted, by selecting structure then assigning background CT number. **Conclusion**: Manually seeds identification and verification are necessary even though there are many automatic seeds searching algorithms proposed. Unlike viewing conventional 2D slice-by-slice CT images, user can visualize the 3D object in any direction and from any position, interactively by zooming, rotating, translating. The seeds being selected will change color for easy recognition.

SU-FF-T-06

Megavoltage CT Imaging Enables CT-Based Low-Doserate Brachytherapy Planning Without CT-Compatible Applicators

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Purpose: To determine feasibility of megavoltage computed tomography (MVCT) imaging for low dose rate (LDR) brachytherapy for cervical carcinoma. **Method and Materials:** A helical tomotherapy treatment unit (Tomotherapy HiArt ,Tomotherapy Inc., Madison, WI) using a nominal 3.5 MV x-ray beam was used to image a dosimetry phantom containing standard, non-CT compatible Fletcher-Suit applicators and dummy Cs-137 tube sources (3M Model 6500). The phantom contained several small steel BB markers which were used as dose points. The MVCT images were transferred to a commercially available treatment planning system (CMS XiO 4.2, Computerized Medical Systems, St. Louis, MO). Digitally reconstructed radiographs (DRRs) were generated from the MVCT data set, and doses (dose rates) were calculated at the phantom dose points using standard 2D, film-based dosimetry methods. Doses were also calculated using a CT-based, 3D dosimetry technique in which the brachytherapy source tips and ends were localized directly on MVCT images. Separate experiments were performed to verify the spatial accuracy of the MVCT image reconstruction in-phantom. **Results:** In-phantom localization accuracy was 0.6 ± 0.3 mm, slightly less than the size of an axial MVCT image pixel and less than half of the MVCT slice thickness. Point doses in-phantom calculated by 2D and by 3D methods agreed within an average of 1.5%. The techniques developed for successful MVCT imaging in-phantom can be used to calculate 3D dose distributions in a human patient undergoing a traditional (non-CT compatible) Fletcher-Suit implant. **Conclusion:** MVCT imaging allows CT-based dosimetry planning without the use of special, "CT-compatible" applicators.

SU-FF-T-07

The Application of Sr-90/Y-90 for the Prevention of Abdominal Adhesions

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Recently, a resurgence in the use of beta particles from $^{90}Sr/^{90}Y$ has occurred, primarily due to its use in intracoronary brachytherapy. $^{90}Sr/^{90}Y$ has also been employed in the ophthalmologic community for postoperative irradiation of pterygia. Due to these successes and other advantageous results of irradiating benign tumors and diseases, a new use for the $^{90}Sr/^{90}Y$ ophthalmologic applicator has been hypothesized: the use of beta radiation for the prevention of abdominal adhesions.

To characterize the source for this use, preliminary measurements were made in a polystyrene phantom using GafChromic film and TLDs. Our results compared favorably with measured values for clinically relevant depths. Upon completion of the phantom measurements, experiments commenced to test the hypothesis in an animal model. Two potential adhesion sites were created in the abdomen of rats via denudation of the serosa of the small intestine. Irradiation of one site with the $^{90}Sr/^{90}Y$ beta applicator occurred; the other site was used as a positive control (no radiation). A 10-day recovery followed, allowing adhesion formation if it occurred; the animals were then euthanized and the injured areas analyzed for efficacy of treatment.

Nine Sprague-Dawley rats were irradiated with varying doses (to determine a dose-response relationship) to a prescribed depth of 1mm. This choice was based on the Novoste clinical trials, clinical treatment depths for the $^{90}Sr/^{90}Y$ applicator, and experimental research on $^{90}Sr/^{90}Y$ beta particles (Buckley *et al*., 2001).

The animals were sacrificed and gross and microscopic pathology was performed. Results show that radiation is effective in preventing adhesion formation. Eight of nine irradiated sections showed no formation of adhesions, while the ninth developed a single adhesion, whereas twelve of thirteen unirradiated sections formed adhesions. The Mann-Whitney U test yielded a p-value of 0.022 confirming the effectiveness of adhesion prevention by the addition of small amounts of beta radiation.

SU-FF-T-08

Tomotherapy Megavoltage Imaging for Gynecological Brachytherapy Treatment Planning and IMRT Integration

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Purpose: To demonstrate the use of the Tomotherapy IMRT system to image the standard shielded Fletcher-Suit applicator for CT based brachytherapy dose calculations and to integrate those dose distributions into Tomotherapy treatment plans. **Method and Materials:** A standard Fletcher-Suit gynecological applicator was placed in phantom and a megavoltage CT scan was done using the Tomotherapy unit. The images were exported in DICOM format to a Pinnacle treatment planning system. Cesium tubes representing a typical tandem and ovoid loading of the applicator were entered into the planning system, and the dose distribution was calculated. The binary dose matrix was then converted to a CT-like file by separating the dose values into individual planes, turning the floating point numbers into 12-bit integers, and adding a header file. Those image files was exported to a Focal Sim viewing station, where the isodose distribution was merged with a phantom CT and contours representing different isosurfaces were drawn. Those contours were exported to the Tomotherapy planning station, were a trial nodal boost volume was drawn in. An IMRT plan was done for this volume, and the resultant Tomotherapy binary dose file was converted to a Pinnacle format in order to be integrated with the brachytherapy plan. **Results:** The megavoltage CT image accurately showed the source holders, tungsten shielding, and flange of the applicator. Exported doses distributions could be integrated with Tomotherapy IMRT. **Conclusion:** The Tomotherapy IMRT system will be useful to accurately image Fletcher-Suit type applicators in actual patients in order to superimpose the dose distributions over the actual patient anatomy. IMRT delivered with Tomotherapy can easily be integrated with brachytherapy with the spread of DICOM dose export. Calculations which take the applicator shielding can be developed because the shielding position is clearly visible.

SU-FF-T-09

Verification of Dose Point Kernels for Ir-192 Brachytherapy

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Abstract

Purpose: A simple method for verifying the dose point kernel of Ir-192 source used in HDR brachytherapy using Kodak EDR2 film in a spiral phantom. **Method and Materials:** A spiral solid water phantom available from Gammex International for IMRT QA was modified for this study. A CT scan image of the phantom was acquired with a 10 x 12 inch film loaded in the spiral groove. A 3.5 mm long 8.5 Ci pellet of Ir-192 in a Nucletron HDR system was driven to a snugly fitting catheter located at the center of the phantom. The film loaded in the groove was exposed for a dwell time calculated to deliver doses within the linear range of the film. A calibration film was processed with each film exposed in the groove. The film was scanned with a Vidar 16-bit scanner and analyzed using the RIT film analysis software. The isodose map and dose profile along the length of the spiral were calculated to a number of selected distances from the center of the source. The conversion of film optical density to dose was procured by measuring the dose at selected points in solid water sheets with a 0.6 cc Farmer ion chamber. The nC recorded at selected distances from the source was converted to cGy using the TG-21 formalism. **Results:** The measured dose point kernel measured with the film was compared with published data. Corrections for obliquity and sensitivity of the chamber with energy were ignored since these are less than 2 %. The dose profile for Ir-192 was found to be in close agreement with published data. **Conclusion:** A simple film exposed in a spiral phantom can be employed to verify the dose point kernels required for Ir-192 and other radionuclides being considered for HDR and LDR brachytherapy.

SU-FF-T-10

Coils, a New Twist for Treatment of Prosate Cancer by Brachytherapy

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Purpose: Pd-103 sources have recently been produced in coil form. These coils offer advantages over conventional seeds including high stability in tissue, better visualization under ultrasound, and more homogeneous dose distribution. We report the first use of Pd-103 coils for treatment of prostate cancer. **Method and Materials:** Fully TG-43 compliant parameters for a 1 cm long source were entered into the treatment planning system and multiples of these 1 cm sources were used to model coils of lengths up to 5 cm. Dosimetry was compared between Theragenics Pd-103 seeds and the new RadioCoil sources. Plans were compared with equivalent geometries, unlike sources placed with their centers matched. Ten patients have been implanted with Pd-103 coils. Intraoperative treatment planning was performed and needles were custom loaded as with conventional seeds. **Results:** The dosimetry of coils is roughly comparable to that of seeds. Required activity of the coils is approximately 8% higher than that of seeds to achieve the same minimum target dose. Even with effectively higher activity per cm, coils deliver a more homogeneous dose distribution with maximum doses to tissues significantly lower than that delivered by seeds. **Conclusion:** Coils are an interesting new source for delivery of therapeutic doses by brachytherapy. They promise better stability in tissues, higher dose homogeneity, and better visualization under ultrasound compared to conventional seeds. Fully compliant TG-43 algorithms are required for accurate dose calculation.

SU-FF-T-11

Dosimetry Comparison of LDR 137Cs and LDR 252Cf Brachytherapy Sources

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Purpose: Hundreds of patients have received gynecological brachytherapy treatments in the US using applicator tube-type (AT) low dose rate (LDR) ^{252}Cf sources. However, its mixed-field radiation dose distributions have not been characterized using the AAPM Task Group 43 dosimetry formalism, nor quantitatively compared to conventional photon-emitting sources. Towards clinical implementation of LDR ^{252}Cf brachytherapy for gynecological applications, the mixed-field dosimetry for this source type has been modeled using Monte Carlo methods and compared to dose distributions produced by LDR ^{137}Cs brachytherapy sources. **Method and Materials:** Mixed-field dose distributions in the vicinity of an AT LDR ^{252}Cf brachytherapy source were calculated using MCNP5 in a 50 cm diameter spherical phantom composed of water, soft tissue, and muscle. ENDF ^{252}Cf neutron energy spectrum was used. Published ^{252}Cf photon energy spectra were employed and compared. The MCNP F4 and F6 calculation tallies were utilized for determining various dosimetric components. These include the source photon, neutron capture photon, fast neutron, and thermal neutron dose components. The LDR ^{137}Cs source used for comparison was the 3M Model 6500. **Results:** Brachytherapy dosimetry parameters for LDR ^{252}Cf neutrons were in agreement with previously published values. TG-43 dosimetry parameters for ^{252}Cf photons exhibited a maximum g(r) value at 10 cm due to induction of capture photons in the phantom and a general decrease in anisotropy with increasing radial distance. ^{252}Cf photon spectra including estimates of delayed photons exhibited –2% difference in g(r) and 5% relative variation in anisotropy at $\theta = 0°$. Dose distributions generated from dosimetry parameters for LDR AT ^{252}Cf were similar to those produced by conventional ^{137}Cs sources using the Pinnacle^3 Planning System. **Conclusion:** Using appropriate radiobiological weighting for ^{252}Cf neutrons, treatment planning for AT LDR ^{252}Cf sources may be performed and compared to conventional ^{137}Cs dosimetry for gynecological applications.

SU-FF-T-12

Experimental and Theoretical Dosimetric Characterization of ADVANTAGETM Pd-103 Brachytherapy Source

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Purpose: Recently, a new design of ^{103}Pd brachytherapy source namely ADVANTAGE™ Pd-103 source has been introduced by IsoAid for interstitial prostate implants. In this project, the dosimetric characteristics of this new source were determined using experimental and theoretical methods, following the updated TG43U1 recommendations. **Method and Materials:** The experimental procedures were performed in Solid Water™ phantoms using LiF TLD dosimetry technique, while the theoretical calculations were performed both in water and Solid Water™ phantom

materials using the PTRAN version 7.43, Monte Carlo simulation code. The photon cross section used for these simulations was DLC-146, distributed by the Radiation Sciences Information Computing Center at Oak Ridge National Laboratory. The dose rate constant, radial dose function, 2D and 1D anisotropy functions of the source were obtained following the TG-43U1 recommendations. **Results:** The results of Monte Carlo simulations indicated a dose rate constant of 0.69 ± 3% $cGyh^{-1}U^{-1}$ and 0.67 ± 3% $cGyh^{-1}U^{-1}$ in water and Solid Water™, respectively. The measured dose rate constant in Solid Water™ was found to be 0.66 ± 8% $cGyh^{-1}U^{-1}$, which is in good agreement with the Monte Carlo results to within the experimental uncertainty. Moreover, the dose rate constant of the new source in water medium, calculated for clinical applications was found to be in excellent agreement with the dose rate constants of the other commercially available sources. A very good agreement between the measured and Monte Carlo simulated, radial dose functions and anisotropy functions were observed. **Conclusion:** The dosimetric characteristics of the newly designed ADVANTAGE™ Pd-103 source were determined as per the TG-43U1 recommendations. The radial dose function, 2D anisotropy function, and dose rate constant were also compared to the other available commercial sources. An excellent agreement was observed on comparison.

SU-FF-T-13

Monte Carlo Calculation of the TG-43 Dosimetric Parameters of a New BEBIG Ir-192 HDR Source

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Purpose: High dose rate (HDR) brachytherapy is a highly extended practice in clinical brachytherapy today. Quality dose rate distribution datasets of the HDR sources used in a clinical treatment are required. Because of the different source designs, a specific dosimetry dataset is required for each source model. In the recently published BRAPHYQS-ESTRO Report, an overview of available dosimetric data for all HDR Ir-192 sources is given, pointing out the lack of data for one of the sources, the used by the BEBIG MultiSource afterloading system (BEBIG GmbH, Germany). The purpose of this study is to obtain detailed dose rate distributions in liquid water media around this source. **Material and methods:** The MC code GEANT4 was used to estimate dose rate in water and air-kerma strength around the Ir-192 source. All the details of the stainless steel encapsulated BEBIG HDR 1.1 mm in external diameter has been included in the simulation. **Results:** A complete dosimetric dataset for the BEBIG Ir-192 HDR source 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. **Conclusion:** The dosimetric parameters and functions obtained for the BEBIG HDR source 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-14

Monte Carlo Derivation of TG-43 Dosimetric Parameters for Radiation Therapy Resources and 3M Cs-137 Sources

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Purpose: In clinical brachytherapy dosimetry a detailed dose rate distribution of the radioactive source in water is needed to make a quality treatment planning. Two Cs-137 sources are considered in this study the Radiation Therapy Resources 67-800 source (Radiation Therapy Resources Inc., Valencia, CA) and the 3M model 6500/6D6C source. **Material and methods:** A complete dosimetric dataset for both sources has been obtained by means of the Monte Carlo GEANT4 code. **Results:** Dose rate distributions are presented in two different ways, following the TG43 formalism and in a 2D rectangular dose rate table. **Conclusion:** This 2D dose rate table is helpful for the TPS quality control and it is fully consistent with the TG43 dose calculation formalism. In this wok, several improvements to the previously published data for these sources have been included: the source asymmetries were taken explicitly into account in the MC calculations, TG43 data were derived directly from MC calculations, the data radial range was increased, the angular grid in the anisotropy function was increased and TG43 data is now consistent with the along and away dose rate table as is recommended by the TG43 Update.

SU-FF-T-15

On the Prescription Dose in Permanent Cs-131 Seed Prostate Implants

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Purpose: Recently, ^{131}Cs seeds have been introduced for prostate permanent seed implants. This type of seed has a relatively short half-life and has its most prominent emitted photon energy peaks in the 29 keV to 34 keV region. Traditionally, 145 Gy and 125 Gy have been prescribed for ^{125}I and ^{103}Pd seed prostate implants, respectively. Since both the half-life and dosimetry characteristics of ^{131}Cs seed are quite different from those of ^{125}I and ^{103}Pd, the appropriate prescription dose for ^{131}Cs seed prostate implant may well be different. This study was to determine an appropriate dose prescription scheme for permanent ^{131}Cs seed prostate implants. **Method and Materials:** A linear quadratic radiobiological model was used in this study. Prostate edema of different durations and sizes was taken into consideration in the dose and tumor cell survival fraction calculations. The tumor cell survival fractions in ^{103}Pd and ^{125}I permanent seed implants were taken as reference values to derive the appropriate dose prescription value for ^{131}Cs seed implants. Calculations were also performed for tumors of different tumor doubling times. **Results:** As expected, the derived prescription dose values were dependent on type of tumors and types of edema. For fast growing tumors, the derived prescription doses were different depending on the type of reference implant was used: ^{125}I or ^{103}Pd seed implant. However, for slow growing tumors such as prostate cancer, the derived prescription dose values were very similar and it was determined that 124 Gy was an appropriate prescription dose for permanent ^{131}Cs seed prostate implants. **Conclusion:** An appropriate prescription dose has been derived for ^{131}Cs permanent seed prostate implants. The dose value was determined to be 124 Gy.

SU-FF-T-16

Treatment Planning Isodose Calculations with the Gliasite Radiation Therapy System

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Purpose: From published data of dose rates and fractional depth doses (FDD) for various sizes of ^{125}I liquid-filled brachytherapy balloon applicators (the Gliasite RTS) we have developed templates of TG-43 compatible dosimetric parameters to be used in computerized treatment planning calculations and isodose generation. **Method and Materials:** The Gliasite radiation therapy system is an intracavitary brachytherapy source that is implanted in brain cavities following excision of the tumor. The balloon can be inflated anywhere between 4 to 35 cc in order to achieve good conformance with the surrounding brain tissue. The initial dose rate in cGy/hr is a function of the balloon size, depth of prescription from the balloon surface and net afterloaded activity in mCi. FDD's, normalized to the balloon surface, are available for determining doses at various depths from the balloon. Based on tables of initial dose rates we have derived the dose rate constant Λ in (cGy/hr.U) at 1 cm from the balloon center for various balloon sizes. We have also calculated a two-dimensional table of the radial dose function g(r) for various balloon sizes and depths in tissue. These dosimetric parameters have then been entered into our brachytherapy planning system (ADAC Pinnacle), where the Gliasite balloon is modeled as a point source. **Results:** Our CT-based three-dimensional dose calculations yield doses to the surrounding normal brain tissue and critical structures. In addition to isodose generation, we also calculate DVH's for critical structures, target volume and normal brain tissue and are able to add doses from external beam or other brachytherapy procedures that a patient may have received. We have spot-checked these isodose calculations using the Gliasite calculation tables. **Conclusion:** CT-based isodose display is useful in assessing doses to neighboring critical structures and is also indicated when the balloon conformance to the surrounding tissue is not optimal.

SU-FF-T-17

3D Monte Carlo-Based Treatment Planning Evaluation of Intracavitary HDR Balloon Catheter Brachytherapy

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Purpose: To evaluate the dosimetric effects of missing tissue and tissue heterogeneities on intracavitary HDR balloon-catheter brachytherapy using a novel 3D Monte Carlo-based treatment planning study. **Method and Materials:** The PTRAN Monte Carlo (MC) photon transport code is used to generate 3D calculations of the doses arising from an HDR ^{192}Ir source in; Anatomy-based MC simulations modeling the dosimetric effects of missing tissue beyond the skin surface and tissue heterogeneities (such as air pockets) adjacent to the balloon catheter (Mammosite); and in a large water phantom representing those calculations achievable with a conventional 3D brachytherapy RTPS. Each MC simulation employs a track length estimator scoring method in a 3D grid, with 2mm resolution in a 12cmx11cmx8cm volume, scoring $8x10^6$ primary photon histories. The dose matrices from all MC simulation are registered (in the external beam module of a commercial RTPS) to a single, modeled patient CT, which is identical in location, scale, and shape to the patient volume described in the anatomy-based MC simulations. Several target volumes (e.g. a 1cm margin on the Mammosite balloon) and a skin-surface contour, are created. Dose-volume histograms (DVH's) are computed for each volume, per each plan. Comparisons of the resultant DVH's quantify the dosimetric errors expected from routine clinical planning of Mammosite applications. **Results:** The missing tissue beyond the skin surface reduces target coverage by 1.5-3.5% and skin doses by 8-20%, when compared to calculations achievable with conventional 3D brachytherapy treatment planning systems. A 10cc airpocket neighboring the Mammosite balloon reduces doses to adjacent tissues <0.5%. **Conclusion:** A detailed 3D Monte Carlo-based brachytherapy RTP study of the dose prediction errors in balloon catheter HDR applications shows that the missing tissue beyond the skin surface reduces skin doses by as much as 20% and target coverage by as much as 3.5%.

SU-FF-T-18

A Simple Theoretical Verification of HDR Calculation Dose Using Point and Line Source Approximation

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Purpose: In order to reduce potential error that can occur in the planning and delivery of brachytherapy treatment, software which is able to be used for three commercial HDR sources was developed. The feasibility of the program was investigated. **Method and Materials:** This windows based program was developed by Visual-Basic language. The TG-43 algorithm was used for the dose computation at interested points. For source geometry, both point source and line source approximations were employed to be capable for most commercial HDR sources. Anisotropy tables for Nucletron microselectron, Gammamed 12i, and Veri Source were included. User is required to select the HDR source type in the beginning of the program, and to enter the number of catheters and dwelling position of a source. The position and the dose at the interested points, such as A and B points, are required to enter. The developed program used the treatment source position and interest point position in the reference frame of the catheters. The computed dose is compared to that in the RTP by calculating the percent dose difference. The accuracy of the code was validated by comparing with commercial RTP computation and hand calculation results for various prototype of treatment ranging from a single catheter to complex multi-catheter plans as well as clinical plans. **Result:** The acceptance levels of performed tests were 5.0% for the percent dose difference at each interested point. For few real patient treatment plans using Nucletron sources, results of the developed program agreed with RTP (Plato, Nucletron) results within 3% error. For Veri Source, large difference between the developed program and RTP was observed if anisotropy was not used in the RTP. **Discussion:** The developed program was adequate for independent dose verification as a part of brachytherapy quality assurance procedure.

SU-FF-T-19

A Study of the Effects of Seed Migration On Prostate Post-Seed Dose Plan Evaluation

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Purpose: Brachytherapy using permanent seed implants has been an effective treatment for prostate cancer. It is a known fact that the seeds will migrate after implant, thus making the evaluation of long-term (e.g. a few weeks) dose distribution difficult. We have performed a sensitivity analysis to determine the impact of seed migration on post-seed dose plan evaluation parameters. **Method and Materials:** The CMS Interplant system and loose Pd-103 seeds are used for the implant. The prostate is implanted with direct ultrasound visualization. CT scan and radiographs are taken 3 hours after the implant. Dosimetric studies are done using Nucletron's Theraplan Plus treatment planning system based on CT images.

The migrations of the seeds are randomly modeled according to Gaussian distribution. The mean migration is taken to be 0.5 cm and the sigma to be 0.25 cm. These numbers are close to latest clinical observations published. To test the sensitivity, an extreme case with mean migration of 1.0 cm and sigma of 0.5 cm is also modeled and compared.

Patients are divided into 3 groups according to the prostate size. For each patient, the seed locations are modeled 10 times for a given mean migration, and the resulting 10 DVHs from the 10 trials are compared. Data are summarized according to prostate size and mean migration. **Results:** Preliminary results shows that D_{100} and D_{90} for prostate change about 3.5% and 2.5% respectively, V_{100} for prostate changes by about 25%, V_{100} and V_{150} for urethra change by about 20% and 50% respectively, and V_{50} for rectum changes by about 15%. **Conclusion:** Dose distribution changes as seed migrate, especially for the volume coverage. This effect should be taken into account when evaluating post-seed plans. Quantitative knowledge of this effect may also factor into the seed distribution in the pre-plan.

SU-FF-T-20

Accuracy of Non-Coplanar Reconstruction of Shielded Colpostats in Intracavitary Brachytherapy

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Purpose: Presence of shields obscures the radiographic visualization of dummy sources by coplanar imaging. In this study a reconstruction method, using non-coplanar images, is tested for clinical use. **Method and Materials:** An isocentric dedicated imaging system with L&C-arm rotation and networked to a treatment planning system (TPS) is used for filmless planning. Testing done by (1) using a 'test phantom' having radiopaque markers separated by known distance (2) using single straight applicator for standardization (3) by orienting the Fletcher-Suit applicator with non-shielded and shielded colpostats to simulate clinical situation. Source position reconstruction was done using orthogonal algorithm for coplanar images and 'IBU reconstruction' algorithm for coplanar & non-coplanar images. Treatment length settings & active dwell positions were pre-fixed . Spatial orientation of dummy source positions, dose-volume histogram, dwell times, total treatment time were all generated. TPS calculated and delivered dose accuracy for both algorithms was checked for the straight applicator by using a 0.13cc ion chamber in a water phantom at various distances. **Results:** Distance variation using 'test phantom' for IBU method was found to be <1mm in the central region & <1.5mm in the corners of the fluoroscopic image and is comparable to the conventional orthogonal method. IBU method was also found to agree with the orthogonal method applicator with respect to source position co-ordinates (<0.5mm), dwell time (<0.3%), total treatment time (<0.3%) and dose-volume histogram analysis. The ratio of measured dose by both algorithms at various distances was close to unity. Reconstructed geometry of shielded colpostats by IBU non-coplanar method was found to visibly match with the "three dimensional" projection. **Conclusion:** Non-coplanar IBU algorithm provides an unambiguous reconstruction method when using shielded colpostats and allows for rapid filmless planning procedure.

SU-FF-T-21

Analysis of Three Optimization Techniques in a Treatment Planning System

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Purpose: To develop the biological and dosimetric based tools for the evaluation of the treatment plans. **Method and Materials:** We have developed a set of treatment planning evaluation tools based on the equivalent uniform dose(EUD), Coverage Index(CI), Homogeneity Index(HI) and Overdose Index(OI) to evaluate the HDR brachytherapy treatment plans. Three different optimization techniques in PLATO treatment planning system are used for CT based 3D conformal brachytherapy: geometric optimization(GO), inverse optimization(IO), and the optimization to the dose points on the surface of the tumor volume(SO). All reference doses are prescribed to the points on the PTV surfaces. Treatment plans of 10 patients are analyzed. **Results:** The GO techniques has the best dose uniformity(mean HI=0.60) but poorest target volume coverage(mean CI=0.71). The SO method provides the best coverage(mean CI=0.85) and lowest homogeneity(mean HI=0.62). The IO plans show a compromise between coverage and dose homogeneity(mean CI=0.52 and HI=0.43). CI and EUD show close correlation for plans produced by all three optimization techniques. **Conclusion:** Our study suggests that these dosimetric indices could be useful tools in the evaluation of the CT based 3D conformal brachytherapy planning.

SU-FF-T-22

Application of Neural Network Algorithm for Treatment Planning Verification of Permanent Prostate Implants

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Purpose: The objective of this project is the evaluation of a software brachytherapy nomogram equivalent. This program was designed to predict the required air kerma strength and source count for implants based on site dimensions and volumes. **Method and Materials:** The nomogram equivalent is based on a three-layer feed-forward neural network (NN). The software consists of two separate programs. One program is used for training the NN and the second program is executed for realizing the nomogram equivalent. The NN was trained using site dimensions, volumes and implanted air kerma strengths for 117 prostate cases. The network was then tested on 30 cases not included in the training set. The results of the NN calculations were also compared with the Anderson nomogram predictions. **Results:** The accuracy of the NN nomogram equivalent is a function of the quality and quantity of training data, the number of iterations set to obtain the desired results, and a consistent source loading methodology. The NN predictions of the total activity and source count are in good agreement (within 11%) with the computer optimized preplanning results for all but two cases. Upon review, significant treatment volume underdosing was observed for these two cases. The Anderson nomogram prediction of the planned total activity was within 13% for all but the two outlier cases. **Conclusion:** The NN based program implemented in the clinic can be an easy, fast, and accurate tool for performing independent verification of interstitial prostate implants. The NN is field-customizable, a capability not possible with a standard nomogram

SU-FF-T-23

Comparison of Chest Radiographs, Fluoroscopy and Seed-Migration Detector for the Detection of Embolized Seeds to the Lung

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Purpose: To evaluate the efficacy of a seed-migration detector and to compare its performance to fluoroscopy and to the postoperative chest radiographs generally recommended. **Method and Materials:** A low energy gamma scintillation survey meter, used together with a count rate meter, was converted to a seed-migration detector. The detector was used to perform a chest evaluation on 155 patients (8717 seeds) at their first postoperative visit. When the detector showed activity around a patient s chest, it was confirmed by taking an antero-posterior chest radiograph and by looking at the region with fluoroscopy. **Results:** 33 patients (21.3%) present at least one embolized seed. That is a 0.47% seed migration rate (41/8717). 37 (90%) of the seeds were visible under fluoroscopy and 28 (68%) appeared on x-rays. Rapid movement of the seeds, due to breathing or to a location close to the heart or the diaphragm, makes nine seeds to be visible with fluoroscopy but not on the radiograph. Moreover, four seeds were not visible with fluoroscopy neither with radiograph. In comparison to the seed-migration detector, detection based on fluoroscopy would have led to four false-negative detections (out of 33 or 12.1%) while the radiograph would have resulted in thirteen (out of 33) false-negative detections or 39.4%. Finally, standard chest x-ray would have required a survey, and extra radiation dose to lung, to 100% of the patients rather than the 21.3% who needed it in this study. **Conclusion:** Because of the high false-negative rate and the superior efficacy of a scintillator-based seed-migration detector, the usual recommendation to perform chest radiographs should be revised. X-rays should remain for documentation purposes of positive cases only. Our clinical experience also allowed us to conclude that the detector is convenient, cost-effective and non-invasive, meaning that it does not require any additional radiation to the patient.

SU-FF-T-24

Comparison of Endobronchial HDR Brachytherapy Using CT Imaging and Conventional Simulator Filming

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Purpose: To compare the clinical merit of endobronchial HDR based on CT imaging and conventional simulator films. **Method and Materials:** The tumor locations within the lung and trachea were first identified and defined with bronchoscopy (FigA). Next a catheter was inserted in conjunction with a dwell position x-ray marker. Subsequently, the patient underwent either simulator filming or CT scanning for HDR treatment planning.

For simulator filming, two orthogonal films were taken to define the tumor location and dose reference points (FigB&C). For CT, the area containing the bronchial target was scanned (FigD). Unlike simulator filming, 3D contouring of the tumor and the reference dose points can be obtained with CT in compliance with actual clinic requirements. Isodose distributions and tumor dose volume histograms (DVH) in both techniques were compared. Results: The simulator filming technique has an advantage of time efficiency. FigC shows the isodose distribution using simulator films. The treatment time durations on each dwell position are fairly constant. Since the tumor volume was defined by estimation, DVHs have little significance. Also, there is a magnification deviation of the tumor volume if the catheter is not always along the gantry axis. For large patients (lateral separation > 40cm), image quality diminishes resulting in uncertainty of isodose distribution coincidence to the tumor.

FigE illustrates the CT images isodose distribution. The isodose distribution in each CT image changes from slice to slice and conformal to the tumor, thus reducing dose toxicity to adjacent tissues. It is in contrast to the monotonic one of the simulator films plan. The DVH is now more significance for analysis. **Conclusions:** Despite procedure time and cost saving with conventional simulator filming, CT imaging is favored for endobronchial HDR in terms of isodose conformity to the tumor and normal functional tissue toxicity reduction.

SU-FF-T-25

Comparison of Intra-Operative Computer Optimized and Nomogram-Based Total Implant Activities in Prostate I-125 Seed Implants

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Purpose: Nomograms correlating total I-125 seed activity, prostatic volume and prescription dose have been published in the literature. In this study, we have retrospectively compared our institutional patient I-125 seed implant activity data with nomogram-based calculations. Our objectives were: (a) to identify if our computer optimized implanted activity data followed any particular nomogram, and (b) to evaluate if implanting adequate activity guaranteed good post-implant dosimetric results. **Method and Materials:** The charts of 255 patients with clinically localized prostate cancer who underwent TRUS guided I-125 seed implantation of the prostate were reviewed. The median pre-implant US prostate volume was 35 cc (range 14 - 82 cc) and the median total activity was 30.9 mCi (range 14.76 – 64.17 mCi). In 95% of the cases, intra-operative

computerized dosimetric planning was performed to optimize the needles, seeds and seed positions. For each patient, a CT-study obtained 1-month after the procedure was used for post-implant dosimetry. **Results:** Our patient implanted activity data was within the range predicted by various nomograms, except in cases where intra-operative computer planning was not used (Fig 1). Implanted activities were dispersed and did not follow activity curve of any specific nomogram. Implanting adequate activity did not always result in good post-implant dosimetry (median D90 value 108.8 Gy, range 31.64 - 256.6 Gy, $p<0.0001$) (Fig 2). CT/US volume ratio >1.5 was associated with decreased D90 (median CT/US ratio 1.51, range 1 – 3.3) ($p<0.0001$) (Fig 3). **Conclusion:** Nomogram calculated and computer optimized activities complement each other, however, intra-operative computerized activity optimization should continue to be the gold standard in prostate seed brachytherapy. Even in properly implanted prostates, discrepancies caused by contouring prostate on US and CT- based images, plus any real volume changes due to edema, significantly influence post-implant dosimetric quality. CT/US-fusion featured on newer planning systems should lessen these contouring uncertainties.

SU-FF-T-26

Comparison of PDR Iridium and LDR Cesium Through Monte Carlo Simulation

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Purpose: Pulsed dose rate (PDR) ^{192}Ir has been proposed as a substitute for intracavitary ^{137}Cs brachytherapy because it radiobiologically mimics LDR treatments. Monte Carlo calculated doses to the ICRU 38 reference points show that PDR delivers a dose distribution that is comparable to that delivered by LDR ^{137}Cs. **Method and Materials:** After validation of the Monte Carlo model using published data for a single source and radiochromic film measurements around a single shielded ovoid, the tandem and ovoid applicator system were modeled using Monte Carlo geometries. Treatment plans using the PDR source were created in Varian's Brachyvision software simulating the isodose shapes produced in a typical Cesium plan. These plans were recreated in Monte Carlo input files. A shielded and an unshielded version of each patient's treatment plan was created to ascertain the effect of the shields on the reference points. **Results:** The results showed that Monte Carlo calculations for the unshielded model to the standard ICRU 38 reference points agreed well with Brachyvision's calculations to these points. Results from the shielded model showed no significant affect to points A and B, but significant change to the bladder and rectal points. An average shielding effect of 12.7% was observed for the bladder point and an average effect of 29.4% was observed for the rectal point.

The results were compared with data from a previous Cesium study involving the same patients. Doses to points A and B were similar. The shielding showed greater effectiveness with PDR for the bladder and rectum. **Conclusion:** A Monte Carlo model was developed to simulate representative clinical dose distributions from a PDR Iridium source in a shielded GYN applicator. The calculations demonstrate that PDR Iridium can be substituted for conventional LDR Cesium brachytherapy.

SU-FF-T-27

Detailed Urethral Dosimetry in the Evaluation of Prostate Brachytherapy-Related Urinary Morbidity

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Purpose: To evaluate the relationship between post-prostate brachytherapy urinary morbidity and urethral doses calculated at the base, mid-prostate, apex and urogenital diaphragm. **Method and Materials:** 186 consecutive patients with no history of transurethral resection underwent monotherapeutic prostate brachytherapy (no external beam radiation or androgen deprivation) with urethral sparing techniques (average urethral dose 100-140% of prescribed dose). The median follow-up was 45.5 months. Urinary morbidity was defined by time to International Prostate Symptom Score (IPSS) resolution, maximum increase in IPSS, catheter dependency, and the need for postimplant surgical intervention. An α-blocker was initiated approximately 2 weeks prior to implantation and continued until the IPSS returned to baseline. Evaluated parameters included overall urethral dose, doses to the base, mid-prostate, apex and urogenital diaphragm, patient age, clinical T-stage, preimplant IPSS, ultrasound volume, isotope, D90 and V100/150/200. **Results:** Of the 186 patients, 176 had the urinary catheter permanently removed on the day zero and only 1 patient required a urinary catheter > 5 days. No patient developed a urethral stricture, and only two patients required a postbrachytherapy TURP. For the entire cohort, mean IPSS peaked 2 weeks following implantation, and the median time to IPSS resolution of 3 weeks. For the entire cohort, only isotope predicted for IPSS resolution, while neither overall average prostatic urethra nor segmental urethral dose predicted for IPSS resolution. The maximum postimplant IPSS increase was best predicted by preimplant IPSS and the maximum apical urethral dose. **Conclusion:** With the use of prophylactic α-blockers and adherence to urethral sparing techniques, urethral dosimetry did not improve the ability to predict urinary morbidity. Neither the average dose to the prostatic urethra nor urethral doses stratified into base, mid-prostate, apex, and urogenital diaphragm segments predicted for IPSS normalization. Radiation doses of 100-140% mPD are well tolerated by all segments of the prostatic urethra.

SU-FF-T-28

Dose Perturbation Effects in Brain Implant Brachytherapy with I-125 Radioactive Seeds

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Purpose: Use Monte Carlo simulations to determine the dose perturbation effects of a single column of radioactive seeds implanted in the brain.
Material and Methods: The EGSnrc Monte Carlo simulation code together with an EGSnrc user code (BRACHYDOSnrc) was used to investigate dose perturbation effects in brain implant brachytheray using ^{125}I. Dose perturbation effects resulting from the mutual attenuation or shielding of other seeds in the implant consisting between 8 and 12 seeds were investigated. The dose perturbation effects were calculated as the difference between the full Monte Carlo simulations taking into account the inhomogeneity caused by the presence of the seeds and the single seed superposition model which ignores the perturbation caused by other seeds in the implant. The seeds were arranged in a single column in a Perspex tubing (end-to-end) and calculation medium was water.
Results: The results show that for ^{125}I. seeds implanted into the brain, with no spacing between seeds, the single superposition dose calculation models underestimates the dose along the longitudinal direction of the seeds by up to 20%. The shielding effects of other seeds causes the dose perturbation which occur generally in the longitudinal direction of the seeds. The volume occupied by the difference in the dose distribution between the full Monte Carlo simulations and simple superposition model increases with increasing number of seeds as expected. The differences in the rest of the calculation grid was generally with ± 5%.
Conclusions The differences between the full Monte Carlo simulations and the single seed superposition dose calculation is not clinically significant as differences occur close to the column of seeds where the dose is already high.

SU-FF-T-29

Dose to the Physician's Extremity During I-125 Prostate Seed Implant Using a Commercial Loading Device

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Purpose: To evaluate a physician's extremity (mainly finger) dose during clinical I-125 prostate seed implants (PSI) using a Mick® loading device. **Method and Materials:** To establish the location of radiation leakage "hot-spots" a piece of XV radiographic film was wrapped around an applicator loaded with a cartridge containing 15 I-125 seeds each with air-kerma strength of 0.44 U. A phantom assembly was developed to simulate the geometry of the interface between the user's hand and this "hot-spot". A piece of radiographic film was placed in the assembly to simulate the location of the user's finger relative to the "hot-spot" and exposed directly or through 1 or 2 layers of radiographic glove material. **Results:** The exposure rate was found to be highest directly below the cartridge, probably due to the presence of small openings in the loader through which body fluids are meant to drain. This location is typically in contact with the physician's finger. For a fully loaded cartridge (15 seeds, air-kerma strength of 0.44 U per seed) it was found that the dose-rate on the surface of the finger is 2.4, 1.1 and 0.4 cGy/hr with 0, 1, and 2 layers of lead glove

material, respectively, between the finger and cartridge. A theoretical calculation of the dose-rate in this geometry gives similar results. **Conclusion:** For a volume of 150 PSI cases per year with 120 seconds of finger contact at the "hot-spot" per case, the annual dose to the surface of the finger is expected to be on the order of 12, 5.6, and 2 cGy when the physician wears no gloves, 1 pair, or 2 pairs of gloves, respectively, well within maximum permissible limits for an extremity. This dose can be effectively reduced to zero if the implant needles are manipulated with no finger contact at the "hot-spot".

SU-FF-T-30

Dosimetric Comparison of Two Techniques for Prostate Brachytherapy Implants

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Purpose: CT based dosimetry was performed one day after prostate cancer treatment by permanent seed implantation. Two techniques were used for implants. To investigate the impact of the two techniques in dose distribution we analyzed several dosimetric ct scans. **Method and Materials:** Patients with prostate cancer were treated with brachytherapy as monotherapy without neoadjunctive androgen deprivation between 01/00 and 12/04. Patient selection in both groups were staging of T1C, pretreatment PSA <8 and Gleason's score of $\leq$ 6; the mean age in both groups was 65 years. Ultrasound volume study was performed two weeks prior to implant procedure. The dosimetry results from 40 patients divided into two groups were analyzed after full dose I-125 implantation. Group one (20 patients) implanted using the Mick Applicator and group two (20 patients) were implanted using the Strand. CT transverse images of the implant volume were collected. Dose volume histogram parameters were analyzed for prostate volume changes, including D 90, V100, and V150. **Results:** The reference dosimetry was performed post-implantation, one day after using computed tomography (CT). Variseed software was used for dosimetric evaluation of each implant to compare the D 90, V100, and V150 dose obtained by the two sets of study. The average prostate volume was 35cm cubed (range 25-59). In group one (using the Mick) the median D 90 was 98.4% (range) and was achieved in 9 out of 20 patients. A comprehensive evaluation is shown in table 1. In group two (using the strand) the median D 90 coverage was 108.5% (range) and was achieved in 14out of 20 patients. An elaborate evaluation is shown in Table 2. **Conclusion:** The above results clearly demonstrate that when we started using the strand we achieved a superior dosimetric outcome that is greater than the minimal therapeutic D 90 value of 140Gy.

SU-FF-T-31

Image Registration of Projected X-Ray Film and CT Image in Brachytherapy Planning

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Purpose: In brachytherapy, film-based planning commonly used for distinguishing the sources accurately whereas transverse imaging modality like CT used for obtaining the organ structure and dose-volume histogram (DVH) directly. In this study, to obtain both advantages of projected x-ray film and CT image, we performed a registration of the coordinates of the film and CT. **Method and Materials:** The 3D reconstruction algorithm for x-ray film was based on the semi-orthogonal method and the registration software developed in IDL 5.5. To verify the registration algorithm, we applied to the humanoid acrylic phantom. The external fiducial marker and the targets, the visible in both films and CT image, attached to the phantom then images acquired. The registration tool provides the coordinates transformation of the pair of orthogonal films and CT image sets. **Results:** The differences in the coordinates of the targets using registration software showed the within 1.5 mm from all directions in the CT scans. (3 mm slice thickness) As film coordinates of the x and y-axis derived from the z-axis of the CT relative to a slice thickness, the uncertainties of x and y was greater than z-axis. **Conclusion:** This method provides the exact positions of the sources and organ positions from registration software. Therefore, it can be a useful and reliable method for treatment planning in brachytherapy planning.

SU-FF-T-32

Imaged-Based Simulation Technique To Determine Stepping Source Dwell Position For MammoSite® Brachytherapy Procedures

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Purpose: Incorrect dwell position for the stepping source in MammoSite® radiation therapy system would result in severe dose error to the treated volume. In many centers, CT-simulators have replaced the fluoroscopic simulators. An alternative method must be developed for this purpose. This project evaluates the feasibility of CT-based simulation to determine the dwell position for the stepping source of the Nucletron® High-Dose Rate (HDR) unit. **Method and Materials:** A MammoSite® balloon applicator is placed in the surgical cavity intraoperatively at the time of segmented mastectomy for breast cancer. The balloon is inflated to near spherical shape with saline solution mixed with a small amount of radiographic contrast to aid in visualization. After recovery, the patient is brought to the radiation oncology facility to determine the quality of the implant and also to determine the stepping source dwell position. A dummy source train is initially inserted in the applicator and pushed to the distal end. The distance is measured using the Nucletron® measuring tool. CT scans of the breast was taken with 1 mm slice thickness. After the images have been acquired, a virtual 3-dimensional breast is generated. Based on the virtual breast, the path of the dummy source train inside the applicator is assessed. **Results:** A digitally reconstructed radiography (DRR) that maximizes the projection of the pathway is created. A method is formulated to determine the center of the sphere and marks on the source pathway. The dwell position is determined by subtracting the difference of distance between the distal seed and center of the sphere from the maximum source distance as set on the HDR unit. **Conclusion:** For institutions where the fluoroscopic simulator has been replaced by a CT-simulator, imaged-based simulation allows an effective method of determining the stepping source dwell position for MammoSite® brachytherapy procedures.

SU-FF-T-33

Introduction to 3-D Image-Based Treatment Planning for Complex Brachytherapy of Soft Tissue Sarcoma

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Purpose: To introduce CT-based treatment planning for brachytherapy of soft tissue sarcoma utilizing 3-D graphics, and to examine resulting improvements in dosimetry and efficiency for complex cases. **Method and Materials:** This procedure begins with a CT scan (Picker PQ 5000) following surgical catheter placement. CT data is transferred to the treatment planning workstation and imported into BrachyVision 6.5 (Varian) software. The catheters are defined as applicators utilizing the combination of 2-D transverse, coronal, and sagittal CT views and 3-D image reconstruction. This type of applicator definition creates automatic seed placement and spacing along the catheter. Ir-192 seeds (Best Industries, Inc.) with TG-43 data are used for dose calculation. Dosimetry is optimized using 3-D dose visualization. This planning procedure has been performed and analyzed on seven LDR and two HDR clinical cases. Two LDR cases were planned with both the previous 2-D method of orthogonal films and the new 3-D CT-based method. The two methods were compared on 3-D versus 2-D (volume versus planar), dosimetry optimization, and clinical feasibility. **Results:** There are significant benefits of using CT-based 3-D planning for sarcoma brachytherapy. CT plane views allow accurate catheter definition and seed placement. 3-D visualization permits an assessment of catheter distribution in more than one plane, and enhances dose optimization for tumor bed dose, hot/cold spots, and normal tissue doses. The process is no more time consuming, and gives more confidence in source placement, more choices in source activity, and improved displays of isodose distributions. **Conclusion:** 3-D compatible planning software with CT imaging has allowed this clinic to improve visualization and dosimetry optimization while reducing uncertainty in seed positioning for complex cases of sarcoma brachytherapy. Use of CT additionally creates the potential of combining dose distributions from external beam treatment and brachytherapy to produce composite dose evaluation.

SU-FF-T-34

Inversely Planned Catheter Positions for High Dose Rate Brachytherapy of the Prostate

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Purpose: To determine the dosimetric impact of the number of catheters used in prostate HDR brachytherapy and to evaluate the possibility of reducing the number currently used clinically. **Method and Materials:** Our in-house inverse planning optimizes the catheter positions based on clinical objectives such as prostate dose coverage, dose homogeneity and urethra protection. This optimization displaces straight catheters on a 5 mm grid searching for the best pattern. The number of catheters is fixed, only their positions and the dwell times are optimized. For one prostate, 8 implants were generated with different number of catheters (5, 6, 8, 10, 12, 14, 16 and 18). **Results:** Implants with more than 10 catheters shows equivalent dosimetric indices with good dose coverage (V100>95%) and low dose delivered to the urethra (V120<5%). With less than 10 catheters the implant dosimetry deteriorates rapidly. The protection of the urethra from high dose (V150=0) is independent of the number of catheters. This demonstrates that decent dose coverage can be achieved with a reduced number of catheters without affecting the urethra protection. The optimization tends to produce implants with peripherally loaded catheters and manages to produce adequate dose coverage with just a few catheters in the middle part of the prostate close to the urethra. **Conclusion:** This study encourages the diminution of the number of catheters implanted around the urethra, improving the urethra protection and facilitating the implant procedure. This is only true when using an inverse planning to optimize the dwell times. Centers that are performing the treatment planning without an inverse planning need these central catheters to produce adequate dose coverage. This demonstrates that inverse planning brings the possibility to safely reduce the number of catheters currently used in prostate HDR brachytherapy.

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SU-FF-T-35

Is High-Dose Rate (HDR) "better Than" and Low-Dose Rate (LDR) Prostate Brachytherapy? A Dosimetric Study Using Retrospective Data.

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Purpose: To compare high-dose rate (HDR) and low-dose rate (LDR permanent seeds) prostate brachytherapy using dosimetric parameters. **Method and Materials:** From January 2003 to August 2004, 102 HDR prostate implants were planned on the Nucletron PLATO Brachytherapy with subsequent treatment using Nucletron afterloader (I^{192} stepping source). During this time period, 72 LDR implants were pre-planned on Varian Variseed Brachytherapy with subsequent treatment using I^{125} seeds (a combination of loose and stranded seeds). The HDR implants were forward planned using a combination of manual dwell time adjustments and graphical optimization on patient CT images. The LDR implants were pre-planned based on ultrasound images and post-implant dosimetry was assessed at one month from CT. For this study, post-plans were analyzed using Nucletron PLATO Brachytherapy Seeds. Parameters used for comparison included: Conformal index (COIN), Homogeneity Index (HI), Natural Dose Ratio (NDR) as well as volume and dose coverage indices. Maximum dose contribution to critical structures was reported. **Results:** Our results show the V100 for HDR with a mean of 96.1% is higher than LDR (post-plan) with a mean of 81.8% ($p<0.001$). Conformal Index for HDR was 0.701 compared to LDR pre-plan (COIN=0.627, $p<0.001$) and post-plan (0.534, $p<0.001$). The homogeneity index showed a significant difference between techniques (HDR HI=0.628, LDR pre-plan HI=0.518, HI post-plan HI=0.425). The Natural Dose Ratio did not show a large difference (HDR NDR=1.025, LDR pre-plan NDR=1.041, LDR post-plan NDR=0.915). **Conclusion**: It has been shown high-dose rate brachytherapy for prostate treatment delivers a more conformal and uniform dose throughout the target than low-dose rate permanent seeds. The dose contribution to the rectum and urethra is much less with high-dose rate than low-dose rate. Dose contribution to the target can be tailored using existing optimization routines and newer algorithms for inverse planning that will make the planning procedure simpler.

SU-FF-T-36

MammoSite Dosimetry Under Condition of Insufficient Buildup and the Proximity of the Balloon to the Lung

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Purpose: Brachytherapy dose planning for MammoSite assumes full scatter buildup. Clinically, MammoSite dosimetry is affected by the buildup condition between the balloon and the skin and the reduced backscatter contribution from the lung. We attempted to answer the following questions: what is the effect of insufficient buildup? What is the dose to the lung? **Method and Materials:** A breast phantom consisting of polystyrene slabs and Styrofoam blocks is constructed. The thickness of slabs may vary to simulate the varying tissues thickness between the balloon surface and skin. Kodak EDR2 films are mounted parallel to the MammoSite catheter between the polystyrene slabs and the Styrofoam blocks. For each thickness of polystyrene slab above the base, the films are irradiated with the same dose. The films are scanned and analyzed by the RIT software. **Results:** The insufficient dose buildup and the lack of backscatter contribution may lead to underdosage at the prescription depth. With only 1 cm tissue above the balloon surface, the minimum dose at the prescription depth is only 75% of the dose under full scatter buildup. Even with 3.5 cm tissue, the dose at 10 mm is only 85%. The lung dose, on the other hand, exhibits a buildup behavior, which varies with the thickness of tissue. As much as 180% of the prescribed dose may be delivered to the lung in the vicinity to the balloon surface. **Conclusion:** The insufficient dose buildup and the presence of lung lead to undersage at the prescription distance which is not revealed in all existing planning system since full scatter buildup without heterogeneity correction is assumed. For correct MammoSite dosimetry, the above issues should be addressed properly. The excessive lung dose even under insufficient dose buildup is may be avoided in some cases by careful placement of the balloon.

SU-FF-T-37

Measurement of Cranio-Caudal Catheter Displacement Between Fractions in CT-Based HDR Brachytherapy of Prostate Cancer

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Purpose: To measure the cranio-caudal displacement of catheters occurring between consecutive fractions of transrectal ultrasound (TRUS) guided high dose rate (HDR) prostate brachytherapy. **Method and Materials:** Ten consecutive patients were treated with 2 fractions of 9.5 Gy TRUS guided HDR brachytherapy using dental putty for the fixation of catheters. For each patient, a CT scan with 3 mm slice thickness was acquired before each of the two fractions. Two different references were employed to measure the catheter displacement between fractions: the ischial bone as a bony marker (BM) and the center of two gold markers (COGM) implanted in the prostate. The catheter displacement was calculated by multiplying the thickness of CT slice with the difference in number of CT slices between the reference slice and the slice containing the tip of a catheter. **Results:** The average (range) magnitude of caudal catheter displacement was 4.1 mm: 2.7 mm (-6.0 to 13.5 mm) for BM method and 5.4 mm (-3.75 to 18.0 mm) for COGM method, respectively. The measurement results obtained from BM and COGM methods verified that both prostate movement and catheter displacement independently occurred between fractions. The most anterior and medial two catheters (catheter position 8 and 12) had the greatest tendency to be displaced in the caudal direction because they were located at the most distant position from the fulcrum, susceptible to the rotation of the dental putty in lateral plane due to patient movement between fractions. **Conclusion:** The catheter displacement using dental putty for the fixation of catheters is smaller than the conventional technique using pre-fabricated template. The use of both BM and COGM methods for catheter displacement measurement can demonstrate the prostate movement relative to the catheter displacement between fractions.

SU-FF-T-38

Measurement of the Radial Dose and the Dose Anisotropy Functions for the New 192Ir Varian Source

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Purpose: To measure the radial dose function and the dose anisotropy functions, used in the AAPM Task Group 43 dose calculation formalism, of the new ^{192}Ir Varian Source model VS-2000 utilized in high dose rate brachytherapy. **Method and Materials:** The measurements were carried out with TLD dosimeters and radiochromic dye films in a 30 x 30 x 30 cm^3 acrylic phantom with the ^{192}Ir source positioned at the center. The new VariSource has an active length of 0.5 cm, and an active diameter of 0.34 mm. Measurements were made for distances between 2 and 7 cm from the source center using TLD-100 (LiF:Mg,Ti) chips (3.1 x 3.1 x 0.89 mm^3) whereas for distances smaller than 2 cm Gafchromic HD-810 film were used. TLD irradiations for each distance from the source center were made separately at approximately 2 Gy. TLD's were read using a Harshaw 3500 reader. Because of the high gradient dose near the source, HD-810 films were exposed at three different doses and then digitized in RBG color scale obtaining three images based on the RGB channels. HD-810 films were calibrated in a ^{60}Co beam. **Results:** Dosimetric characteristics of the new Varian ^{192}Ir source have been measured in an acrylic phantom using LiF TLD chips and HD-810 radiochromic film. These measurements were performed following the AAPM TG-43 task group recommendation. The radial dose and the dose anisotropy functions were measured in the range of 0.25 cm to 1.5 cm using HD-810 radiochromic film and for distances between 2.0 cm and 7 cm using LiF TLD-100 chips. The anisotropy function was measured from 5° to 180° relative to the source axis. **Conclusion:** Dosimetry data were presented for the new Varian ^{192}Ir HDR source following the AAPM TG-43 dosimetric formalism, for input and verification purposes in treatment planning systems.

SU-FF-T-39

Mono-Energetic Brachytherapy Sources

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Purpose: Determination of the energy dependence of human cell inactivation (i.e., loss of reproductive capacity) following exposure to β radiation. **Method and Materials:** A dipole magnet was constructed from two 5.08cm x 5.08cm x 2.54cm niobium permanent magnets separated by a distance of about 2cm. This dipole has a highly non-uniform field that reaches about 5 kG at the center. A 1cm x 1cm collimated electron beam exiting a ^{137}Cs radioactive source (300 Ci, max energy: 662 keV) was placed at the entrance face of the dipole magnet. Separation of the different energies was ensured by placing a second identical collimator perpendicular to the dispersive plane. The setup provides an energy resolution of about 10%. Four normal human fibroblast (AGO1521, AGO1522, GM06419 and WI-38) and one human breast cancer (MDA231) cell line were exposed to electrons of defined energy for approximately 1 hour (~3.5 Gy). Radiation induced changes in clonogenic survival were determined and protein samples collected for subsequent proteomic analysis using 2D gel electrophoresis, coupled with Mass Spectroscopic identification of candidate proteins. **Results:** Examination of the Relative Biological Effectiveness of the various electron beam energies on human cell lines indicates an energy dependence of cell inactivation. The radiation exposure time variation and the type of cell lines play a non-negligible role in the experimental outcome. Preliminary Monte Carlo simulation data of the process at the molecular level compare fairly well with experimental results. **Conclusion:** This work indicates the potential efficacy of providing mono-energetic radioactive sources for Brachytherapy treatments. Characteristic responses of tumor cells to well defined kinetic energies of β particles could reduce the incidence of unwanted side effects associated with ineffective radiation dose. The methodology will be used in future investigations on small animals to establish in-vivo applicability of the technique.

SU-FF-T-40

Monte Carlo Calculation of Pd-103 Prostate Implant Treatment Plan

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Purpose: A ^{103}Pd TheraSeed® Model 200 prostate implant treatment plan calculation based on TG-43 formalism will be compared to a Monte Carlo (MCNPX) simulation of the treatment plan complete with detailed seed geometry. Dose contour lines as well as specific dose points will be compared. **Method and Materials:** Co-ordinates from typical pre-plan treatment plans were used to set up 3-D Monte Carlo simulations of a small prostate (84 seeds) and a medium prostate (107 seeds). The seeds were modeled in full geometric detail and placed in a 50 cm sphere of water. The Model 200 seed geometry was previously benchmarked in a single seed configuration against published TG-43 dosimetry parameters. Surface Crossing Tallies and Energy Deposition Tallies were used to calculate dose at specific points for comparison to dose points calculated in treatment planning software. Mesh tallies were used to create isodose lines for comparison to those calculated by the TG-43 based treatment planning software. MCNPX flux values were converted to absolute dose based on NIST measured Air Kerma Strength and NIST measured contained activity measurements of TheraSeed® Model 200. **Results:** Comparison of the 75, 100, 110, 150, and 200% isodose lines for a series of planes within the treatment area yielded reasonable agreement. As expected some variation from the treatment planning software isodose lines is seen due to attenuation from surrounding seeds as well as differences in the dose distribution surrounding the seeds. Selected dose points along the urethra yielded dose values with a maximum deviation of 20% between the treatment planning software and Monte Carlo calculation. **Conclusion:** Full three dimensional Monte Carlo modeling of a typical treatment plan is possible in order to make dose comparisons to TG-43 based formalism calculations for a typical treatment plan configuration. **Conflict of Interest:** Corresponding author is an employee of Theragenics Corporation®.

SU-FF-T-41

Monte Carlo Dosimetric Study of the New BEBIG Co-60 HDR Source

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Purpose: The use of high dose rate brachytherapy (HDR) is a highly extended practice today, being the Ir-192 the most widely extended isotope used for this type of practice although Co-60 is also available for HDR. The purpose of this study is to obtain the dosimetric parameters of the Co-60 source used by the BEBIG MultiSource remote afterloader (BEBIG GmbH, Germany) for which there is no dosimetric data available in the literature. It is recommended that accurate dose distribution data, based on a realistic geometry and on the mechanical characteristics of the source, should be obtained by an appropriate method, experimental or Monte Carlo, to be used as input in the HDR Treatment Planning System. **Method and Materials:** The Monte Carlo code GEANT4 has been used to obtain the TG43 parameters and the 2-D rectangular dose rate table of the BEBIG Co-60 HDR source. **Results:** The dose rate constant, radial dose function and anisotropy function have been calculated and are presented in tabular form as well as a detailed 2-D rectangular dose rate table to check the treatment planning systems calculations. **Conclusion:** A Monte Carlo dosimetric study of the BEBIG ^{60}Co HDR source for which no published dosimetric data exists has been done. These dosimetric datasets can be used as input and/or to validate the TPS calculations.

SU-FF-T-42

Monte Carlo Study of Delivered Dose as a Function of Applicator Material in HDR Brachytherapy

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Purpose: Intracavitary HDR brachytherapy is used to treat gynecological tumors. Our system was first delivered with acrylic cylindrical applicators but these were sensitive to heat sterilization and were replaced with Delrin. We note the density of these materials increases from 1.19 g/cm^3 to 1.43 g/cm^3. We investigate the effect of the higher density applicators on the delivered dose distribution using Monte Carlo calculations. **Method and Materials:** Doses were calculated with the EGSnrc system, using DOSRZNRC. The cylinders, tandem tubes, transfer guide tubes, and the source wire were modeled as concentric open cylinders. For full backscatter, the phantom was modeled as water outside the cylinder to a minimum distance of 22 cm from the outer surface of the applicator. Primary and secondary emitted photons were followed down to a cutoff

energy of 1 keV, and Compton scattered electrons were followed down to 10 keV. Total accumulated dose was scored at the surface of each cylinder and at 5 mm and 10 mm from the surface. All clinically available cylinders from 2 cm to 4 cm diameter and for both materials were modeled. Twelve and a half billion histories were run for each study. **Results:** Dose to the points of interest varied from 0.5% to 1.5% between the two materials with the dose at the points of interest being higher for acrylic cylinders than for Delrin. The differences are a function of cylinder size with the largest difference seen in the 4 cm diameter cylinders. **Conclusion:** The change in material from acrylic to Delrin results in systematically decreased dose to the patient. This decrease in dose is a function of cylinder size but is not large enough to be clinically significant. We recommend using the Delrin cylinders as they are more easily sterilized between uses.

SU-FF-T-43

Objective Comparison of RAPID Strand and Free SelectSeeds Loading for Permanent Prostate Implants Using An Inverse Planning Approach

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Purpose: To quantify differences in treatment plans of permanent implants between RAPID strand™ and free selectSeed™ loading patterns. **Method and Materials:** The 3-D US scan and treatment plan from ten patients who have been treated for prostate cancer with the permanent seed implant technique were arbitrary selected. The plans were generated manually by an experienced dosimetrist backed up by a team. Essentially the RAPID strand™ seed-loading pattern was used. Retrospectively the patients were re-planned with a commercial 3-D planning system (SPOT-PRO™ 3.0) using the new inverse planning algorithm (IPSA). A plan with a RAPID strand loading pattern (IPSA-R) was generated and a plan with a free seed-loading pattern (IPSA-F). **Results:** The calculation time of IPSA was < 15 s for 400,000 iterations (2.5 GHz PC), which is fast enough to be used intra-operatively. The target coverage V_{100} was equal (98–99%) for all plans. The target and urethra DVHs of the manual and the IPSA-R plan were similar. By contrast the urethra doses D_{40}, D_{30}, D_{20}, D_{10}, and D_{max} of the free seed plan IPSA-F were 27–41 Gy lower than in the RAPID strand plan IPSA-R. **Conclusion:** When using free seeds instead of RAPID strands, the urethra dose is significantly reduced.

Conflict of Interest: Part of this research was supported by Nucletron B.V., Veenendaal, The Netherlands

Keywords: Seeds, I-125, Inverse planning, selectSeed, RAPID Strand

SU-FF-T-44

Optimized Source Selection for Low Dose Rate Brachytherapy

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Purpose: To introduce the method of the optimized source selection for the LDR Brachytherapy, and investigate its effectiveness as compared to the regular trial and error source selection. **Method and Materials:** An in-house method of optimized source strength ratios was developed to replace the trial and error guess work for the LDR therapy with sealed Sc-137 sources. Inverse treatment planning philosophy was applied to the whole process. The desired dose to the reference points is first specified. The corresponding optimal plan is then defined, and the source selection program is run to produce an actual loading plan with the available sources. These actual sources are then used to calculate the final dose distribution. Treatment plans obtained with this method were compared to the plans obtained with the regular technique. Also optimal plans produced by our method were compared to the actual plans selected by the segmentation algorithm. **Results:** The difference between the optimal and the actual plans is determined by the available inventory. In our tests we achieved a relative difference a few percent at the expense of the dose rate. We noticed a significant difference between the regular plans and optimized plans. The regular method produced clinically acceptable plans after several iterations. The results depend on the personal experience. With our method the desired 3D dose distribution was achieved at a first try. **Conclusion:** Utilizing our source selection method treatment plans closest to the clinically optimal can be produced in a short amount of time. The results are independent of the personal experience and the most limiting factor was the discreteness of the available inventory. Keeping the statistics on the frequently requested source strengths for the optimal plans helps in ordering the clinically relevant replacement or additional sources, and minimizing the quantity of idle sources in the inventory.

SU-FF-T-45

Partial Volume Analysis in Permanent Seed Implantations

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Purpose: Permanent seed implantation is a well accepted therapy for the treatment of low risk prostate cancer. In Europe the number of treated patients increases considerably. New techniques and planning systems allow a very safe intervention. A retrospective analysis is performed to show if there are additional parameters to optimize dose distribution and therefore to reduce side effects. **Method and Materials:** In our institution 304 patients were implanted with I-125 radioactive seeds following the recommendations of the ABS and the ESTRO/EORTC for a permanent prostate brachytherapy. Basis for the dosimetry was an ultrasound guided intraoperative interactive real-time planning (VariSeed 6.7/7.0/7.1). Looking for coherences between dose distribution and side effects a partial volume analysis was performed particularly in the apical and basal part of the prostate. Dosimetric data analyzed were V100, V150, D90 and the mean dose. **Results:** Postoperative follow-up is 1-54 months (mean 24 months). Different types of side effects such as urinary retention, proctitis, and erectile dysfunction occurred in 4%, 8% and 24% of our patients. Looking to the group with and without side effects we found relevant differences in the apical part of the prostate. The median for the V150 (apex) is 40,5% and 28,8%, the mean dose in the apex is 283,1Gy and 257,5Gy. The D90 and V100 is comparable in both groups (184,1Gy/182,3Gy, 98,9%/99,2%). No significant differences were found in the basal part of the prostate. **Conclusion:** A partial volume analysis of the prostate during the implantation offers the possibility to lower side effects. It is not sufficient to look to the standard values such as V100, D90 for the prostate and D30 and V100 for the urethra and rectum. Looking more into detail for the dose distribution a better dose homogeneity with a better quality of life for the patient can be achieved.

SU-FF-T-46

Performance of Xoft FlexiShieldTM Flexible X-Ray Shielding in Laboratory Tests and in a Goat Mammary Model

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Purpose: These studies measured the low energy x-ray shielding effectiveness of Xoft FlexiShield™ flexible tungsten-silicone sheets. The ability of the shielding material to lower the ambient radiation level in a treatment room was then evaluated during dose delivery to goats in the course of simulated accelerated partial breast irradiation (APBI). **Method and Materials:** X-ray attenuation of 1 mm thick tungsten-silicone flexible sheeting was measured using a collimated beam from a Xoft AXXENT™ X-ray Source operated at 30 to 50 kV. X-ray attenuation was calculated as the ratio of air kerma rate from the Source measured using an Exradin A600 Ionization Chamber with and without the shield in the beam path. To evaluate shielding effectiveness in a clinical setting, exposure rate was measured during simulated APBI of four Nubian milk goats with balloon applicators inserted percutaneously into simulated lumpectomy cavities in their udders. A Victoreen 451B Ion Chamber Survey Meter was used to measure exposure rates at twelve locations with nominal distances of 1 meter from the udder being treated. **Results:** X-ray attenuation measured using the collimated beam was 10^4 to 10^6 at 30 to 50 kV operating voltage. A calculated lead-equivalence of 0.45 mm at 50 kVp was based on the equivalent of 0.35 mm thick tungsten in the 1.0 mm thick composite sheet. During dose delivery to goat udders draped with FlexiShield™ the average ambient exposure rates at 1 m were 1.3 and 13 mR per hour at 40 and 50 kV operating voltages, respectively. The exposure rate at 50 kV was 170x lower than without shielding. **Conclusion:** Xoft FlexiShield™ flexible tungsten-silicone sheet is a conformable low energy x-ray shield that very effectively reduces the ambient exposure rate while performing APBI. **Conflict of Interest:** Research was supported by Xoft, Inc.

SU-FF-T-47

Phantom Study of Radiation Dose Reduction to the Contralateral Breast Using Lead Shielding When Treating with the MammoSite Applicator

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Purpose: Accelerated intracavitary partial breast irradiation can be delivered using an Ir-192 HDR afterloader with a MammoSite™ applicator. Over the course of a 3400 cGy treatment the contralateral breast can receive total radiation doses exceeding 200 cGy. Placing shielding between the breasts might reduce the dose to the contralateral breast. Phantom measurements were performed to investigate the feasibility and benefit of this shielding. **Method and Materials:** Treatments were simulated using doses of 340 cGy. Dose measurements were performed using an ion chamber in a homogeneous solid water phantom. The ion chamber was calibrated is solid water 5 cm from a known Ir-192 source. The phantom was simulating a geometrically simple patient with 5 cm tissue from the center of the MammoSite balloon to the medial breast surface, 10 cm of air between the breasts, and 1 cm to the measurement point in the contralateral breast. 1.6 mm lead sheets were used in single or double layers. The simulations were repeated in a Rando™ anthropomorphic phantom with simulated breasts created from BolxII™. **Results:** Contralateral breast shielding is strongly dependant upon the position of the Ir-192 source and the lead shield. Using 1.6 mm and 3.2 mm of lead reduced the contralateral breast dose behind the shield by approximately 45% and 65% respectively. In our Rando™ experiments, using 3.2 mm of lead, the dose 1 cm below the skin would decrease from 190 cGy to 57 cGy and the dose at the center of the breast from 101 cGy to 39 cGy **Conclusion:** A 3.2 mm lead shield decreases the dose to the contralateral breast by more than 60%. This may be clinically significant for a reduction in the risk of radiation-induced second malignancies. Shielding may be of best use if treating the patient in a prone or sitting position.

SU-FF-T-48

Prognostic Significance of Perineural Invasion On Biochemical Progression-Free Survival Following Prostate Brachytherapy

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Purpose: To evaluate the influence of perineural invasion (PNI) in the biopsy specimen on biochemical progression-free survival in hormone naïve prostate brachytherapy patients. **Method and Materials:** From 1995 through 2001, 512 consecutive hormone naïve patients (173 low-risk, 212 intermediate risk, and 127 high-risk) underwent permanent brachytherapy for clinical stage T1b-T2c NxM0 prostate cancer. All patients underwent brachytherapy at least 3 years prior to analysis. The median follow-up was 5.3 years. Biochemical progression-free survival was defined by a PSA cutpoint $\leq$ 0.4 ng/mL after nadir and by the ASTRO consensus definition. PNI was defined as carcinoma tracking along or around a nerve within the perineural space. Clinical, treatment and dosimetric parameters evaluated for biochemical progression-free survival included PNI, age, PSA, Gleason score, percent positive biopsies, prostate volume, brachytherapy planning volume, V100/150/200, D90, supplemental external beam radiation therapy, tobacco consumption, BMI, hypertension and diabetes. **Results:** PNI was documented in 133 patients (26.0%). Regardless of which biochemical progression-free definition was used, 94.0% and 94.9% of patients with and without PNI remained free of biochemical progression. The median time to failure in patients with and without PNI was 17.2 months and 17.9 months respectively. For the entire biochemically disease-free cohort, the median post-treatment PSA was < 0.1 ng/mL. In univariate Cox regression analysis, pretreatment PSA, percent positive biopsies, prostate volume and Gleason score predicted for biochemical outcome. PNI did not approach statistical significance (p = 0.671). In multivariate analysis, only pretreatment PSA (p < 0.001) and percent positive biopsies (p < 0.001) maintained statistical significance. **Conclusion:** In hormone naïve brachytherapy patients implanted with generous periprostatic treatment margins, the presence of PNI in the biopsy specimen did not adversely impact 8-year biochemical progression-free survival. PNI is not an independent indicator for ADT in prostate brachytherapy patients.

SU-FF-T-49

Prostate Brachytherapy-Induced Urethral Strictures

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Purpose: To determine the incidence and to identify clinical, treatment and dosimetric parameters associated with the development of urethral strictures following permanent prostate brachytherapy. **Method and Materials:** From April 1995 through May 2003, 1186 consecutive patients underwent permanent prostate brachytherapy for clinical stage T1b-T3a NxM0 (2002 AJCC) prostate cancer. Nine hundred and twelve patients (76.9%) were implanted with Pd-103 and 204 (23.1%) with I-125. The median follow-up was 4.3 years. Follow-up was calculated from the date of implantation. Clinical, treatment and dosimetric parameters evaluated for bulbomembranous urethral strictures included patient age, prostate volume, the use of supplemental XRT, isotope, androgen deprivation therapy (ADT), duration of ADT, prostate V100/150/200, D90, prostatic urethral dose (mean, median and maximum), bulbomembranous urethral dose (mean, median and maximum), tobacco use, hypertension, diabetes and BMI. **Results:** Twenty-nine patients developed brachytherapy-induced strictures and all occurred within the first 5 years following brachytherapy. All strictures involved the bulbomembranous urethra. The 9-year actuarial risk of bulbomembranous urethral strictures was 3.6% with a median time to development of 34 months. The radiation dose to the bulbomembranous urethra was significantly greater in patients with strictures than those without (p < 0.001). In addition, the urethral dose 15 mm distal to the prostate apex was significantly greater in patients with strictures (p < 0.001). In multivariate analysis, only the bulbomembranous urethral dose and the duration of ADT (> 6 months) predicted for the development of a urethral stricture. All patients were successfully managed by either a urethral dilatation or internal optical urethrotomy. **Conclusion:** Brachytherapy-related urethral strictures are related to overaggressive implantation of the periapical region and prolonged (> 6 months) treatment with ADT. Careful attention to preplanning and intraoperative execution, along with the judicious use of ADT, is essential to minimize the incidence of brachytherapy-related strictures.

SU-FF-T-50

Reduction of Computed Tomography Metal Artifacts Due to I-125 Seeds for Post Implant Analysis in Prostate Permanent Brachytherapy

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Purpose: Postimplant analysis in I-125 permanent brachytherapy for prostate cancer plays important role in improving the techniques of implant. Although American Brachytherapy Society recommends CT based postimplant analysis, the identification of prostate bundle is quite difficult. In addition, metal artifacts from the I-125 seeds implanted make it more difficult to identify the prostate. Thus accuracy of the dosimetric parameters associated with volume of prostate such as D90 and V100 may be unclear. The purpose of this study is to mitigate CT metal artifacts due to I-125 seeds to provide more accurate postimplant analysis. **Method and Materials:** The prostate phantom that was implanted 3 to 10 seeds per a plane was scanned using 16-detector raw CT. The sinogram was modified by our algorithm that is similar to projection-interpolation method to CT images containing artifacts from I-125 seeds. The regions of projection data existing I-125 seeds were identified by observing differences of X-ray intensity between the phantom and the seeds. Then the regions were interpolated to remove the metal artifacts. The new images were reconstructed with the corrected sinogram. We compared these with the CT images that are corrected by commercially available metal artifact reduction method. **Results:** The metal artifacts caused by a small number of I-125 seeds were completely eliminated by our correcting method. On the other hand, the magnitude of the artifact with the commercially available method was insufficient. With regard to many seeds in the same plane, the metal artifact was mitigated by our method although the contrast of images was degraded. **Conclusion:** Our method would mitigate metal artifacts caused by I-125 seeds and be helpful to identify prostate. Although some problems have still remained to improve, our approaches would be adapted to clinical field

SU-FF-T-51

Relationship Between Isotope, Prostate Volume and Urinary Morbidity Following Prostate Brachytherapy

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Purpose: To evaluate the influence of isotope and prostate size on International Prostate Symptom Score (IPSS) normalization, catheter dependency and the need for surgical intervention following permanent prostate brachytherapy. **Method and Materials:** 976 consecutive patients underwent permanent brachytherapy for clinical stage T1b-T3a prostate cancer. Of these, 789 were implanted with Pd-103 and 187 with I-125. Patients were stratified into size cohorts ≤ 25.0 cm^3, 25-35 cm^3, 35-45 cm^3, and > 45.0 cm^3. 418 received androgen deprivation therapy (ADT). 486 received supplemental external beam radiation therapy (XRT). In all patients, an α-blocker was initiated prior to implantation and continued until the IPSS returned to baseline. The median number of IPSS determinations per patient was 21. Clinical, treatment and dosimetric parameters evaluated included patient age, pretreatment PSA, Gleason score, clinical T-stage, percent positive biopsies, preimplant IPSS, ultrasound volume, planning volume, isotope, $V_{100/150/200}$, D_{90}, urethral dose, supplemental XRT, ADT, and the duration of ADT (≤ 6 months versus > 6 months). **Results:** For both isotopes and all size cohorts, IPSS peaked 1 month following implantation and returned to baseline at a mean of 1.9 months. Stratification of prostate size cohorts by isotope resulted in no significant differences in prolonged catheter dependency, IPSS resolution or postimplant surgical intervention. In Cox regression analysis, IPSS normalization was best predicted by preimplant IPSS, XRT and any need for a catheter following brachytherapy. Catheter dependency correlated with prostate volume, while the need for surgical intervention was related to catheter dependency, maximum urethral dose, ADT and maximum IPSS increase. **Conclusion:** When stratified by prostate size, the choice of isotope did not impact IPSS resolution, catheter dependency or the need for postbrachytherapy surgical intervention. While prostate size did predict for short-term (< 5 day) catheter dependency, it did not influence IPSS resolution or the need for surgical intervention.

SU-FF-T-52

Selecting Patients with a Pretreatment Post-Void Residual Urine < 100 Cc May Favorably Influence Brachytherapy-Related Urinary Morbidity

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Purpose: To evaluate the relationship between pretreatment post-void residual urine (PVR) < 100 cc and brachytherapy-related urinary morbidity. **Method and Materials:** 204 patients with a pretreatment PVR underwent permanent prostate brachytherapy with urethral sparing techniques (100-140% mPD). Patients were stratified into pretreatment PVR cohorts ≤ 20 cc, 20-50 cc, and ≥ 50 cc. In all patients, an alpha blocker was initiated prior to implantation and continued until the International Prostate Symptom Score (IPSS) returned to baseline. IPSS resolution was defined as a return to within 1 point of baseline. Clinical, treatment and dosimetric parameters evaluated included pretreatment PVR, patient age, PSA, Gleason score, clinical T-stage, risk group, preimplant IPSS, ultrasound volume, planning volume, isotope, values of the minimum dose received by 90% of the prostate gland (D_{90}), the percent of the prostate volume receiving 100%, 150% and 200% of the prescribed mPD ($V_{100/150/200}$), urethral dose, pretreatment TURP, hypertension, diabetes and tobacco status. Catheter dependency and the need for postsurgical intervention were also evaluated. **Results:** In patients with a pretreatment PVR < 106 cc, stratification into PVR cohorts ≤ 20 cc, 20-50 cc, and ≥ 50 cc did not predict for meaningful differences in urinary morbidity. For the entire cohort, the mean time to IPSS resolution was 2.5 months. The urinary catheter was removed on the day of implantation in 171 patients (83.8%) with no patient remaining catheter dependent for > 3 days. In multivariate analysis, pretreatment PVR predicted for clinically irrelevant differences in IPSS resolution and did not influence catheter dependency. To date, no patient has required postimplant surgical intervention. **Conclusion:** The selection of patients with a pretreatment PVR urine < 100 cc was associated with rapid IPSS resolution, the absence of prolonged (> 3 day) catheter dependency, and the elimination of post-brachytherapy surgical intervention for bladder outlet obstruction.

SU-FF-T-53

The Impact of Primary Gleason Grade On Biochemical Outcome Following Brachytherapy for Hormone Naïve Gleason Score 7 Prostate Cancer

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Purpose: Biochemical outcome in Gleason score 7 patients with dominant pattern 4 histology is thought to be inferior to those Gleason score 7 patients with primary Gleason grade 3, based on conclusions from radical prostatectomy studies. In this study, we evaluate the effect of the dominant histologic pattern in Gleason score 7 prostate cancer on biochemical progression-free survival following prostate brachytherapy. **Method and Materials:** 273 consecutive Gleason score patients underwent permanent interstitial brachytherapy for prostate cancer without androgen deprivation therapy. All patients underwent brachytherapy more than 3 years prior to analysis. Biochemical progression-free survival was defined by a PSA cutpoint ≤ 0.4 ng/mL after nadir or by the ASTRO consensus definition. The median follow-up was 4.7 years. Clinical, treatment and dosimetric parameters evaluated for biochemical progression-free survival included primary Gleason grade, clinical T-stage, pretreatment PSA, risk group, percent positive biopsies, perineural invasion, patient age, isotope, supplemental XRT, prostate volume, brachytherapy planning volume, the percent of the target volume receiving 100%, 150%, and 200% of the prescribed dose (V100/150/200), the minimum percent of the prescribed dose covering 90% of the target volume (D90), tobacco consumption, hypertension and diabetes. **Results:** The actuarial 8-year biochemical progression-free survival rate was 94.5% and 94.8% using either a PSA cutpoint ≤ 0.4 ng/mL after nadir or the ASTRO consensus definition, respectively. For biochemically disease-free patients, the median posttreatment PSA was < 0.1 ng/mL. When stratified by the dominant histologic pattern, no statistical difference in outcome was noted for any of the evaluated parameters. In forward conditional Cox regression analysis, pretreatment PSA and percent positive biopsies were statistically significant predictors of biochemical outcome. **Conclusion:** In hormone naïve Gleason score 7 patients, prostate brachytherapy results in a high probability of 8-year biochemical progression-free survival and is independent of Gleason 3+4 versus 4+3 histology.

SU-FF-T-54

Treatment Planning in HDR Intracavitary Brachytherapy: Comparison of Critical Organ Doses as Estimated by Orthogonal Radiographs Based Planning and Image Based Planning

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Purpose: Doses to rectum, bladder and Point-A in patients who received intracavitary HDR brachytherapy treatment were calculated by both orthogonal radiographs reconstruction method and by image based reconstruction method and were compared. **Method and Materials:** Twenty-five patients of carcinoma cervix who received intracavitary brachytherapy treatment by micro-Selectron HDR unit were included in this study. For these patients, in Plato treatment planning system, reconstruction of sources, applicator, organs at risk and Point-A were done using conventional orthogonal radiographs and by using 1 mm thick CT scan images. Bladder was identified on radiographs through a Foley's catheter inserted into it filled with 7 cc of radio-opaque fluid and the rectum through a rectal marker. Doses were calculated at 5 points each on bladder and rectum, for the treatment dose of 7 Gy to Point-A (right & left). On CT images, these organs were delineated with the radiologists help and from dose-volume-histograms, doses to 1, 2 and 5 cc of these organs were calculated besides dose to Point-A (right & left). **Results:** The critical organ doses estimated by the CT method were consistently higher when compared to those by the radiographs method. When compared to the radiographic dose maximum for bladder, doses to 1, 2 and 5 cc of bladder were higher by 89%, 69.7% and 41.6% on an average respectively. For rectum, the corresponding values were 36.6%, 21.7% and 0.4%. However dose to Point-A did not differ by more than 3% between the two methods. **Conclusion:** The conventional orthogonal radiography based reconstruction method consistently underestimates the doses to critical organs while the doses to reference points are comparable in these two methods. Long-term follow-up in such patients can identify the threshold

volumes for these critical organs beyond which complication rates are bound to rise.

SU-FF-T-55

Variability of Prostate Brachytherapy Preimplant Dosimetry: A Multi-Institutional Analysis

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Purpose: To conduct a multi-institutional comparison of prostate brachytherapy preimplant dosimetry for Pd-103 and I-125. **Method and Materials:** Eight experienced brachytherapists submitted Pd-103 and I-125 monotherapeutic and boost preimplant dosimetry plans for central review. All 32 plans were calculated using the same transrectal ultrasound volumetric study. Seeds of any strength were acceptable, but were restricted to two manufacturers. The dosimetric analysis included evaluation of target volume, target to prostate ratio, target length, number of needles, seed activity, number of seeds, total activity, total activity per treatment planning volume, use of extracapsular seeds, and average treatment margins (distance between the prostate capsule and the 100% isodose). Prostate coverage was defined in terms of V100/150/ 200/300 and D100/90/50 while urethral dosimetry consisted of UV100/150/200 and UD90/50. **Results:** The mean planning target volume to prostate volume ratio varied dramatically (mean 1.29, range 0.99 – 1.76) with the target length ranging from 3.5 to 4.5 cm. Although the prostate V100 was > 95% in all cases, the V150 ranged from 29.9 to 92.1% and the V200 from 6.72% to 52.5%. The urethra V100 was 100% in all cases, with 6 of the 8 brachytherapists limiting the UV150 to < 3%. However, the median urethral dose varied by up to 50%. Treatment margins also varied significantly (average 3.98 mm, range 0.32 – 7.68 mm). All brachytherapists used extracapsular seeds with five implanting > 25% of the seeds in extracapsular locations (range 6.4% - 58.2%). In addition, significant variability existed in the number of needles, the number of seeds, and seed strength. **Conclusion:** This study highlights that although prostate brachytherapy prescription doses are uniform, substantial variability exists regarding target volume, seed strength, dose homogeneity, treatment margins and extracapsular seed placement. The standardization of preimplant dosimetry is essential for meaningful multi-institutional comparisons of biochemical outcomes and morbidity.

SU-FF-T-56

Verifying Correct Location of HDR Source Dwell Position in the MammoSite Catheter Using An Integral Linear MOSFET Dosimeter Array

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Purpose: Correct centering of the HDR source with the spherical MammoSite balloon is critical for proper brachytherapy delivery. We tested a MammoSite modified to incorporate a linear MOSFET dosimeter array to assess whether real-time dosimetry measurements could confirm HDR source centering in MammoSite catheters. Method and Materials: A "MammoSite with MOSFETs" was simulated using a linear MOSFET array (Thomson Nielsen) consisting of 2 MOSFETs at the end of a flexible strip spaced 4 cm apart. The MOSFET array was placed along an uninflated 6-French endobronchial catheter within a water-equivalent solid phantom. This arrangement simulated having the detectors along the source pathway of a MammoSite, with the detectors within the balloon. The first detector was located at distal end of the "MammoSite" and the second at the proximal balloon collar. The HDR source was programmed to dwell at various positions relative to the "center" and MOSFET readings were obtained. Also, a prototype "MammoSite with MOSFETs" was built with the MOSFET array in a lumen adjacent to the source lumen. The scatter conditions (i.e., variable skin thicknesses) have been assessed by proximal MOSFET readings at various depths in a water phantom. **Results:** Ratio of the distal and proximal MOSFETs' readings showed high sensitivity to changes in dwell position. The fractional standard deviation of the ratio ranged from 0.9% to 3.2%, while each 1 mm shift from center caused at least 15% change in ratio. These ratios were not strongly affected by dose, dose rate, or nearby scatter media. **Conclusion:** The "MammoSite with MOSFETs" showed the potential to dosimetrically verify HDR source position with a linear resolution of 1mm or better. Further investigations are warranted to make this a routine clinical tool. **Conflict of Interest:** AH, Employed by Thomson-Nielsen. JS, BS, MW, employed by Proxima Therapeutics.

SU-FF-T-57

A COIN-Based Comprehensive Specification Index for IMRT Treatment Plans

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Purpose: The purpose of this work is to formulate a single index that can be used to specify the relative merit of an IMRT treatment plan for prostate carcinoma. The index includes components for conformity, tolerance, and uniformity and also serves to analytically determine the optimum normalization required for unbiased plan comparison. **Method and Materials:** COIN = C1*C2*C3 has been used to evaluate HDR and EBRT plans. C1 and C2 are planning target volume and normal tissue conformity metrics. C3 accounts for the irradiation of critical structures. An ASTRO prostate patient CT and contour data set were used as a case study. Nominal 76 Gy plans were calculated on a commercial system and DVHs exported to a PC using an in-house program. All IMRT plans were calculated with the same dose-volume constraints and then normalized to give the maximum COIN value. C3critical is calculated for the specific rectal tolerance dose of 65Gy. The COIN integral is a measure of dose inhomogeneity. A term C4 = [1- COINintegral(1.02) / COINintegral(1.00)] is introduced to account for two percent relative hot spots. The Comprehensive Specification Index CSI = C1*C2*C3critical*C4 is the proposed figure of merit. **Results:** All CSI values were calculated relative to 100 for the 9-field plan. Respective CSI values for a static 4-field, ideal fluence 5 and two 7-field IMRT plans were 44.5, 97.1, 99.6, and 91.8. After conversion to deliverable step-and-shoot segments with 0.5 and 1.0 cm MLCs, CSI value for the 9-field plan was reduced to 75.7 and 53.1. **Conclusion:** An index CSI was formulated and used to specify the relative merit of analytically normalized prostate IMRT plans. CSI is a sensitive figure of merit capable of distinguishing plans with various field arrangements and able to quantify the effect of converting ideal IMRT fluence to deliverable segments.

SU-FF-T-58

A Comparison Between Helical Tomotherapy and LINAC-Based Fractionated Cranial Radiosurgery Treatments Utilizing RTOG Guidelines

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Purpose: An evaluation of helical Tomotherapy fractionated cranial radiosurgery treatment based on RTOG stereotactic radiosurgery indices for dose coverage (C), conformality (CI) and homogeneity (HI). A comparison between helical Tomotherapy and LINAC-based non-coplanar arc systems utilizing actual clinical cases. **Methods & Materials:** Clinical cases presenting with varying target sites, tumor volumes, and risk of complication (i.e. proximity of target to OAR) are evaluated. For each case two separate treatment plans, consisting of the best achievable optimized plan from the Tomotherapy planning system, and from a LINAC-based radiosurgery planning system (Pinnacle ADAC) are compared. Coverage of the complete (100%) PTV volume is given highest priority during the treatment planning with both systems. **Results:** The dose coverage obtained from both planning systems is very comparable and range from 97 to 99%. However, in terms of dose conformality and homogeneity the Tomotherapy planning system resulted in superior treatment plans for every patient evaluated in the study. The CI and HI values for the Tomotherapy plans ranged from 1.01 to 1.39 and from 1.02 to 1.12 respectively. Whereas the CI and HI values obtained from the LINAC-based plans ranged from 1.36 to 2.14, and from 1.88 to 2.98 respectively. **Conclusion:** For all the cases evaluated the helical Tomotherapy system easily complied with RTOG stereotactic radiosurgery standards for dose coverage, conformality

and homogeneity. Whereas target coverage defined as a percentage of the prescribed dose, is comparable between helical Tomotherapy and LINAC-based non-coplanar arcs, significantly better conformality and homogeneity are obtained with the Tomotherapy system (especially for large and irregularly-shaped tumors). The examples presented illustrate a default behavior of the TomoTherapy optimizer that is not employed in conventional radiosurgery planning, specifically the ability to deliver uniform dose to the target volume at the expense of increasing the low doses to the surrounding tissue.

SU-FF-T-59

A Comparison of Forward and Inverse Planned IMRT Treatment of Breast Cancer

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Purpose: To compare a forward planning technique with a commercial inverse planning module for breast IMRT treatments. **Method and Materials:** Currently, our clinic uses the Pinnacle IMRT InvPlan module for left breast IMRT treatment planning. Before the planning, the treatment volume (TV), the heart and the lungs are contoured on the patient CT scans. The isocenter and two tangential fields are defined in our treatment planning system (TPS), and an IMRT treatment plan was then generated using the inverse planning module. For the purpose of this study, we created forward planned IMRT breast plans with the same isocenter and tangential beams. Beam intensities in the forward plan were modulated by adding "control points" (CP), a special functionality provided by Pinnacle TPS. CP combines multiple tangential beams into a step-and-shoot IMRT field with multiple segments. A tangential beam in a forward IMRT breast plan typically consists of one open segment and 4 MLC segments blocking hot spots. A typical inverse IMRT breast plan has 6 to 7 segments in each beam. Isodose distributions and DVH's were compared between the breast IMRT plans generated using the forward planning technique and the inverse planning module. The statistical results were examined for the TV volumes receiving 95%, 100% and 105% of the prescription dose, the lung volume receiving more than 20 Gy and the heart volume receiving more than 30 Gy. **Results:** Five left breast cases were studied. The DVH's generated from both methods were comparable. It was found that the forward planned breast IMRT plans used fewer segments. The average values for V95, V100 and V105 between forward and inverse planed IMRT breast plans were within 2%. **Conclusion:** The forward planning technique can generate comparable breast IMRT plans and these plans met the clinical constraints used in our IMRT breast protocol.

SU-FF-T-60

A Dosimetric Comparison of Three Commercially Available Carbon Fiber Table Extension Boards

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Purpose: To measure and compare the changes in dose distributions produced by the presence of a carbon fiber extension board (used to provide necessary patient extension beyond the gun end of the treatment couch). The tested carbon fiber extension boards are designed to be "radiotranslucent" so that the transmitted radiation beam is not significantly altered. We measured the attenuation due to the boards being placed in the beam's path, compared the relative dose distributions obtained using different boards, and also examined the effect of "build-up". **Method and Materials:** The three boards evaluated were the Med-Tec Type-S system, the Brainscan H&N Tx system, and the Orfit HP long baseplate for IMRT. Dosimetric data were obtained for 6 MV photons with an Exradin A12, 0.65 cm^3 Farmer ionization chamber, with Kodak EDR film, and with an Exradin P11, 0.62 cm^3 plane parallel chamber (for measuring dose buildup in a Gammex RMI solid water phantom). **Results:** The Orfit board's maximum attenuation was 1.2%. The Med-Tec Type-S board's maximum attenuation was 2.3%. The Brainscan board's maximum attenuation was 13.7%. The isodose distribution and profiles for each board will be presented. **Conclusion:** We determined that the Orfit board did not significantly alter the radiation beam and resulting dose distribution. Its adaptability to various tables was favorable compared to the Med-Tec system, which is well suited for the Varian Exact couch. The Med-Tec board is also well suited for therapeutic radiation, but had a higher change in attenuation than the Orfit system. The Brainscan board was sub-optimal due to non-air equivalent material used as structural support in the board's interior, which caused significant beam attenuation. **Conflict of Interest:** Research was supported by equipment loan from Orfit Industries and Med-Tec, Inc.

SU-FF-T-61

A Pseudo-Tangential IMRT Technique for the Whole Large Left Breast Radiation Therapy Using Helios/Eclipse System

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Purpose: A pseudo-tangential IMRT (PT-IMRT) technique was developed to achieve high dose uniformity for the whole large left breast (separations >24 cm and volumes > 1200cc) radiation therapy and to reduce the early and late skin and subcutaneous reactions. **Method and Materials:** The proposed PT-IMRT technique basically combines two pairs of tangential beams with two additional beams angled less than 10 degree from each side. In most situations, the two additional beams were angled anterior to the tangential plane. An additional OAR was drawn around the high dose (>110%) area at the lateral side. The PT-IMRT is an inverse planning approach. After the optimization, 2 cm skin flash was added to each beam. Multiple static segments were used for the IMRT delivery. For comparison purpose, four other plans were also run for each patient: an inverse tangential-IMRT plan (T-IMRT), a 3D plan, a forward field-in-field (FIF) plan and a forward electronic compensator (EC) plan (all use the tangential beams only.) In-homogeneity correction was included in all plans. Dose volume histogram (DVH) was used for the evaluation of all plans. **Results:** The PT-IMRT provided the best dose volume uniformity for PTV. The dose volume to heart and left lung for doses less than 15 Gy was 2-3% higher for PT-IMRT, but was 2-3% lower for doses larger than 25 Gy. The dose increment to a point 1 cm deep and 5 cm right to the mid-sternum inside the right breast was 2-5% higher compared to other four plans. The normal tissue volume for doses larger than 105% was significantly reduced with the PT-IMRT compared to the other four plans. **Conclusion:** The PT-IMRT resulted in the most homogenous dose distribution among all the five techniques and has the potential to reduce the early and late skin and subcutaneous reactions.

SU-FF-T-62

Anatomy-Based MLC Field Optimization for the Treatment of Gynecologic Malignancies

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Purpose: To evaluate the use of a new inverse planning system with anatomy-based field segmentation, as an alternative between "4-field box" and beamlet-based IMRT, to treat whole pelvis of women with resected gynecologic malignancies. **Method and Materials:** A solution has been elaborated with the assistance of an in-house optimization tool named *Ballista*. This inverse planning system can generate anatomy-based MLC fields and simultaneously optimize their orientation and weight. The selected geometry consists of 7 coplanar and 2 noncoplanar incidences. For 10 patients planned to receive 45 Gy for resected endometrial or cervix neoplasia, target volume and organ at risk (bowel, region "at risk to find bowel" (B RAR), bladder, rectum, bone marrow) were delineated. Using the *Pinnacle*[3] planning system, four plans were generated for each patient: conventional 4-field, enlarged 4-field (aperture shaped to PTV),"step-and-shoot" IMRT and *Ballista* plans. Dose-volume histograms, number of segments and monitor units (MU) were analyzed. **Results:** Planning target volume (PTV) coverage was similar for enlarged 4-field, IMRT and *Ballista* plans, and follows the ICRU standard recommendations. Only 77.5 ± 1.9% (mean ± SEM) of PTV received the prescription dose if conventional plans were applied ($p<0.001$). The mean volume of B RAR receiving 45 Gy was: 4-field, 49.7 ± 7.1%; enlarged 4-field, 63.4 ± 5.8%; IMRT, 26.4 ± 3.1%; *Ballista*, 29.0 ± 3.0%. No statistical difference was noted between the ability of IMRT and *Ballista* to spare bowel ($p=0.14$), while *Ballista* plans were better than 4-field ($p<0.001$). The mean number of segments for *Ballista* was 33.3 ± 2.3 vs 128.6 ± 2.6 for IMRT and the mean number of MU was 325.0 ± 11.8 vs 731.5 ± 25.0. **Conclusion:** Weight optimization, with anatomy-based MLC fields, is a good alternative

between manual planning and IMRT for the treatment of gynecologic malignancies. Clinical results of treatment tolerance will follow.

SU-FF-T-63

Breast IMRT Based On Direct Aperture Optimization

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Purpose: To investigate the advantages of DAO (Direct Aperture Optimization) based IMRT planning for breast cancer. **Method and Materials:** The IMRT plans were generated, using a DAO algorithm implemented in a commercial planning system (Panther, PROWESS), for 5 breast cancer patients who were treated in our clinic with 3D conformal plans. These 3D plans were produced by the Xio planning system (CMS) employing 4-6 tangential beams of different energies and wedges. In addition, we generated another IMRT plan for each of these patients using a beamlet-based conventional IMRT planning system (Xio, CMS). Both the DAO and beamlet-based IMRT plans employed two opposite tangential beam directions with about 70% of the dose delivered with stationary fields covering whole breast with 2-3 cm of flash. The target volume for all plans was the whole breast tissue; boost PTVs were not considered. All plans were done with homogeneous density calculation. The three sets of plans, DAO IMRT, 3D and beamlet IMRT, were compared in terms of dose uniformity, hot spots, normal tissue sparing, number of segments and MUs. **Results:** The results show that: 1) dose uniformity and coverage of breast is improved significantly with either IMRT methods compared to 3D, DAO method providing slightly better coverage than conventional beamlet method, 2) hot spots typical for an IMRT plan with a large number of segments are significantly reduced, for the DAO plan, 3) number of segments and MUs with the DAO plan were significantly less than those for beamlet IMRT plan. Also, the planning time for a DAO plan is short compared to a 3D plan which involves a search of multiple wedges and energies by a trial-and error method. **Conclusion:** DAO based IMRT planning is capable of generating superior IMRT plans for breast irradiation, in terms of dosimetric criteria and delivery efficiency.

SU-FF-T-64

Combined Electron and Photon Intensity Modulated Radiotherapy for the Management of Malignant Pleural Mesothelioma

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Purpose: This study investigated the feasibility and potential benefits of combining electron and photon intensity modulated radiotherapy (IMRT) for patients with malignant pleural mesothelioma (MPM). Complex-shaped MPMs are difficult to treat by conventional radiotherapy due to low tolerance doses of the surrounding normal tissues. Even with recent treatment techniques employing photon IMRT, doses to the critical structures are difficult to keep within tolerance. **Method and Materials:** Two MPM patients after extrapleural pneumonectomy were studied. The patients were planned with photon IMRT alone and photon IMRT combined with electrons. The latter approach incorporated the electron component into the inverse planning optimization. The resulting doses to the planning target volume (PTV) and relevant critical structures were compared. For both plans**,** 54 Gy was delivered to the PTV that includes non-uniform margins along the clinical target volume (CTV), ranging from 3 mm along the spine to 6 mm near the ribcage. **Results:** Target dose coverage for both techniques was optimal (D95, V95 > 98%) while the doses to the critical structures were minimal (liver D50 < 27 Gy, contralateral lung and kidney D80 < 15 Gy, ipsilateral kidney D50 within 15-18 Gy). However, combined electron and photon IMRT exhibited an advantage in reducing the doses to the liver and ipsilateral kidney by an additional 10% while the PTV hot spot was reduced by 10%. The planning and setup time with the addition of electrons is expected to be longer. **Conclusion:** This study showed that photon IMRT alone or combined with electrons are viable treatment modalities for MPM patients. Both plans can provide excellent target coverage and normal tissue sparing, but with the addition of electron beams the critical structures can be further spared. Additional investigation to optimize the electron contribution to these complicated plans would be expected to result in further improvement.

SU-FF-T-65

Comparison of Dose to Rectum and Bladder with 3DCRT and IMRT Plans for the Treatment of Prostate

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Purpose: Major goal of IMRT is to escalate dose to prostate while keeping doses to bladder and rectum equal to or less than that with 3DCRT. This study is to compare 3DCRT and IMRT to evaluate how far this goal has been achieved. **Method and Materials:** Dosimetry of 6-field 3DCRT and 5-field IMRT plans, generated for the same 32 patients, has been compared. With 3DCRT, prescription to SV and prostate was 45 and 75.6 Gy, respectively. With IMRT, prescription to SV and prostate was 45 and 81 Gy, respectively. IMRT required to keep doses to 30%, 50% and 70% of bladder and rectum less than 70%, 60% and 40% of 81 Gy and to cover 95% PTV with 95% isodose. Dose to rectum and bladder were estimated from DVH. Less than 5% difference in rectal and bladder doses between 3DCRT and IMRT was considered insignificant. **Results:** Higher the dose to rectum and bladder with 3DCRT, higher also was the dose with IMRT ($P<0.001$). Dose to 50% rectum with IMRT was equal to that with 3DCRT in 15 cases (47%) and more in 17 cases (53%). Dose to 10% of rectum with IMRT was equal to that with 3DCRT in 9 cases (28%) and more in 23 cases (72%). Dose to 50% and 10% bladder with IMRT were equal to that with 3DCRT in 7 cases (22%) and more in 25 cases (78%). **Conclusion:** Preliminary analysis suggested that the space between rectum and prostate+SV, and the volume of rectum and bladder in beams path are related to doses to these structures. Higher doses to rectum and bladder with IMRT are a result of trade-off between doses to PTV, rectum and bladder. This may be acceptable because percent dose coverage to 95% PTV is better with IMRT (93-98%) than with 3DCRT (86-93%).

SU-FF-T-66

Comparison of IMRT Plans with Tissue Heterogeneity Corrections Using the Pinnacle3 and CORVUS Treatment Planning Systems

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Purpose: To study and compare the results of IMRT plans with tissue heterogeneity corrections using the Pinnacle^3 and CORVUS treatment planning systems (TPS). **Method and Materials:** A 30 cm x 30 cm x 15 cm solid water phantom embedded with a 7.5 cm styrofoam slab simulating air was scanned on Siemens Emotion Duo and the image set was transferred to both TPS for dose computation and analysis. A few clinical cases planned on the CORVUS were also transferred to Pinnacle^3 and computed with heterogeneity corrections. **Results:** The dose profile along the central axis of a 23MV beam inside phantom was generated on both TPS and was compared with the Battista et al[1] data from TG65. It is noted that a gradual build-up effect after the in homogeneity region in the case of Pinnacle^3 but it is not noticed in the case of CORVUS. In the case of clinical lung plan, CORVUS overestimated the dose homogeneity and uniformity in the target when compared to Pinnacle^3 TPS. When re-optimized and re-computed on Pinnacle^3 TPS, the target coverage on DVH was better than CORVUS. Discrepancies of 33% (relative to the prescribed target dose) in the target region were found in CORVUS TPS calculations. **Conclusion:** The FSPB algorithm as implemented in CORVUS results in significant under- or over-estimation of the dose in some cases involving heterogeneities such as the air-tissue, and lung-tissue. Comparatively, the convolution algorithm in Pinnacle^3 is far superior and takes into account the electronic disequilibrium due to tissue heterogeneity. This is in agreement with earlier published literature using Monte Carlo computations.

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SU-FF-T-67

Comparison of Linac Based Fractionated Stereotactic Radiotherapy and Tomotherapy for Treatment of Skull-Base Tumors

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Purpose: To compare and evaluate Tomotherapy and linac based fractionated stereotactic radiotherapy (FSRT) techniques in the treatment of lesions located in the base of skull. **Method and Materials:** Five patients

with skull-base tumors, originally planned for optical guided FSRT to prescribed doses of 50.4 to 54Gy were replanned using TomoTherapy treatment planning software. All original CT scans, MR-CT fusion defined contours for target and normal structures, and PTV margins were used for Tomotherapy planning. Linac based plans utilized one of the following FSRT planning techniques: non-coplanar or coplanar intensity modulated radiation therapy (IMRT), multiple non-coplanar conformal arcs, and non-coplanar conformal radiation therapy (CRT). These plans were used as the gold standard to which the Tomotherapy plans were compared. **Results:** Use of both linac based FSRT and helical tomotherapy generated highly conformal treatment plans. Criteria used for comparison included prescription isodose to target volume (PITV) ratios, inhomogeneity index (II), equivalent uniform dose (EUD) for PTV's, mean normalized total doses (NTD_{mean}) for critical structures, and size of 10, 20, and 30Gy isodose volumes. Non-coplanar linac based plans exhibited a 23% to 50% decrease in PITV ratios, increased II, similar EUD, and generally comparable to improved NTD_{mean} for critical structures when compared to helical tomotherapy, which are coplanar by nature. Use of non-coplanar field arrangements also resulted in a 14% to 72% reduction of these low dose isodose volumes when compared Tomotherapy. All criteria except for the II, which was much improved with Tomotherapy, were found to be similar when coplanar linac based plans were compared to helical tomotherapy plans. **Conclusion:** Results show a distinct advantage in using non-coplanar beam arrangements for treatment of skull-base tumors. In the case where disease spreads far inferiorly, limiting the ability to use non-coplanar arrangements, Tomotherapy can be used to generate a comparable treatment plan.

SU-FF-T-68

Conformal Target Versus Conformal Avoidance IMRT in Patients with Prostate Cancers

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Purpose: To compare conformal avoidance IMRT with conformal target IMRT for the radiotherapy of prostate cancers. **Method and Materials:** Twenty patients with prostate cancer who underwent IMRT were selected for this study. For comparison, five plans were generated for each patient with different emphasis on conformal target or conformal avoidance: very conformal target IMRT plan (Plan I, maximum weights for targets and least weights for OARs), conformal target IMRT plan (Plan II, maximum weights for targets and relatively small weights for OARs), balanced IMRT plan (Plan III, maximum weights for targets and medium weights for OARs), conformal avoidance IMRT plan (Plan IV, maximum weights for targets and relatively large weights for OARs) and very conformal avoidance IMRT plan (Plan V, maximum weights for both targets and OARs). All the five plans were designed to deliver 66.6 Gy (prescription dose) to 100% of the CTV. **Results:** The target dose coverage became worse as plan changed from very conformal target to very conformal avoidance, as 100% isodose line cut more and more through PTV adjacent to rectum. On the other hand, the rectum sparing increased at the same time, due to the increased emphasis on the avoidance of OARs. Overall, all the five plan schemes achieved the goal of delivering 66.6 Gy to the whole CTV. However, Plan IV was slightly better than the rest of plans in terms of largest CTV V100 (99.90%), best homogeneity in CTV dose distributions (smallest difference between Dmax and Dmin) and smallest Rectum D25 (58.88 Gy). **Conclusion:** For prostate IMRT, practicing conformal avoidance in inverse planning process can achieve better target dose coverage and homogeneity, as well as larger critical structure sparing.

SU-FF-T-69

Determining Patient Eligibility for Prostate IMRT Dose Painting Protocols: The Role of Image Resolution, Margin Requirements, and Intraprostatic Tumor Volume

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Purpose: To systematically examine the impact of margin and imaging resolution on dose painting protocols with regards to target definition and patient eligibility. **Method and Materials:** The prostate PTV was formed by expanding the clinical target volume by 1-cm. The intraprostatic tumor nodules (IPTNs) were digitized using data from Chen et al.(2000) corresponding to a >50% probability of occurrence. The IPTNs were then discretized on three different grids: $1mm^2$ (our treatment planning pixel size), $2mm^2$, and $6.6mm^2$; grid sizes reflect imaging modality resolution. 75.6Gy was prescribed to the PTV and the target dose for the IPTNs was 90Gy. Our standard rectal and bladder constraints were used with maximum dose of 91Gy to rectum and urethra. The margin on the tumor nodules was varied from 0.2 to 1.5cm. **Results:** The volumes for the IPTNs were 3.2, 4.9 and 10.2cc for the three grid sizes; CTV and PTV volumes for the whole gland were 44.2cc and 137.2cc. A typical distribution of IPTNs (4 foci), expanded with a 6mm symmetrical margin to 33cc was boosted to 90 cGy without exceeding critical organ constraints. Margins were 5mm and 5.5mm with grids applied. Once the absolute volume of the targets (IPTNs + margin) was accounted for, however, neither grid size nor margin size had an impact on the ability to escalate dose. The ratio of the boost region to the PTV volume was the determining factor. The limiting IPTNs+margin volume was 25% of the PTV volume. By relaxing the requirements to accept >90% coverage with 90Gy, acceptable plans could be achieved with IPTNs+margin volumes occupying $\leq$36% of the PTV volume. **Conclusion:** A simple volume-based screening method may be used to determine patient eligibility for inclusion in a clinical IPTN dose-escalation study, irrespective of the cancer-specific imaging system's resolution and required margins.

SU-FF-T-70

Dosimetric Comparison of Inhomogeniety Corrections in IMRT Treatment Planning Systems: A Collaborative Study

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Purpose: A multi-institution collaborative study of dosimetric comparison of inhomogeneity corrections in IMRT treatment planning systems. Nine institutions representing twelve IMRT systems participated in this study. **Method and Materials:** DICOM RT data sets for prostate, lung, and head and neck cases with target volumes and the organ at risks (OAR) already outlined were sent to each collaborative member. Beam arrangements, dose volume constraints and a maximum grid size were kept constant. For the case of prostate, lung and head and neck cases, 7, 5 and 9 equally placed field arrangements, were chosen for treatment planning using a 6 MV beam. Treatment plans were generated and optimized to meet the benchmark clinical endpoints. Each of the cases was calculated with and without inhomogeneity corrections. The calculated DVH's, phantom plans and measured data were collected and analyzed. **Results:** Traditionally, utilizing modern treatment planning algorithms, there are significant differences in conformal 3D RTP, especially in head and neck and lung cases. Across all of the systems analyzed in this study, however, our data was quite the opposite. DVH analysis of PTV/CTV and critical organs show virtually identical data for homogeneity corrected vs. uncorrected iterations. The ratio of MU's across several IMRT TPS for corrected and uncorrected iterations for lung and head & neck cases were within 5% of each other. **Conclusions:** The overall conclusion from the data analysis reveals that although the target coverage, total MU's, treatment delivery times etc. may vary significantly from one IMRT TPS manufacturer to another, most systems are able to generate clinically acceptable optimal solutions for both homogeneity corrected and uncorrected calculations. More importantly, the variation in target/critical organ coverage for inhomogeneity corrected vs. uncorrected iterations is minimal and the clinical impact of these variations should also be consequently minimal.

SU-FF-T-71

Effect of Daily Shifts of IMRT Prostate Patients On Dose to Pelvic Nodes

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Purpose: Pelvic lymph nodes are often incorporated en bloc with the

prostate as targets in radiation treatment. It is common practice to realign the fields daily before each treatment to account for prostate motion; however, pelvic nodes are relatively immobile such that adjusting the radiation fields to track the prostate may lead to a geographic miss of the nodes. Here, we explore the magnitude of this problem. **Method and Materials:** Information from two patients was used in this analysis. IMRT plans were created using the NOMOS/Corvus system and PTVs extending 1.0 cm about the nodes CTV in all directions were planned to 45 Gy in only 25 of the approximately 40 total fractions. Daily field shifts were made by pretreatment ultrasounds of the prostate using the B-mode acquisition and targeting system. Dose of each shift was recalculated using Corvus and the results analyzed using Matlab and CERR. In addition, a random number generator used a clustered probability distribution derived from the total 40 or so shifts to produce alternative scenarios to the 25 shifts. This allowed evaluation of multiple scenarios without need for further timely dose calculation. **Results:** In all simulations, the cumulative dose over all shifts showed little under-dosage, most of which was at the histogram's tail. For the 90% CTV volume there was a reduction of around 0.7% of prescribed dose. In shifted plans the maximums of each fraction no longer overlap in the same tissue so that most under dosage is expected to be at the histogram's tail. **Conclusion:** These results suggest that current PTV expansions are adequate to provide prescribed dose coverage of CTVs. It may be possible to further refine PTV expansion definitions to reduce radiation to normal tissues while maintaining treatment delivery to target tissues without causing a geographic miss.

SU-FF-T-72

Effect of Number of Beams On Dose Gradients and Quality of IMRT Plans

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Purpose: To investigate the dose gradient as a function of number of beams and the role of beam angle selection in IMRT plans **Method and Materials:** A hypothetical tumor and an organ-at-risk (OAR) were created in a cylindrical phantom, with two different tumor-OAR distances: 3mm and 7mm. For each tumor-OAR arrangement, 22 plans with different beam configurations were generated using 3, 4, 6, 9 and 15 equally spaced beam angles. 6 additional plans were created for the beam number of 3, 4 and 6 using selected beam directions based on tumor-OAR geometry. All plans were compared based on the same dose coverage to the tumor, the plan conformal index, dose gradient (defined by the minimum distance between the 90% and 20% of iso-dose lines), maximum dose and mean dose to the OAR. **Results:** The dose gradient is linearly broadened as the number of beams is increased. The plan conformal index is rapidly improved from 3 to 6 beam angles. The maximum dose (defined as $D_{1\%}$) to the OAR is linearly decreased as the number of beams is increased while the mean dose to the OAR is decreased only from 3 to 9 beam angles. When compared to the equally spaced beam directions for a given number of beam angles, the selected beam angles can only improve the mean dose to the OAR. **Conclusion:** Using more beams in IMRT plans can improve plan conformality and reduce maximum dose and mean dose to the OAR, but it may broaden the dose gradient, which is defined as a minimum distance from 90% to 20% isodose lines. The tumor-OAR geometry is not a good indicator for beam angle selection in IMRT planning. **Conflict of Interest:** Research is supported in part by Prowess Inc.

SU-FF-T-73

Effects of Beam Energies On IMRT Treatments of Large-Sized Prostate Patients

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Purpose: The energy dependence of intensity modulated beams for prostate cancer treatments has been extensively reported for regular sized patients. In this study, we evaluate whether 6-MV intensity modulated beams can be used for treating large sized patients ($\geq$ 25 cm in anterior-posterior separation and $\geq$ 35 cm in lateral separation). **Method and Materials:** Five prostate patients with AP separations of 25 to 34 cm and lateral separations of 35 to 47 cm were planned for IMRT treatments. Each patient was planned with 6-MV and 18-MV beams for comparison. The plans were optimized using identical dose volume constraints on a commercial treatment planning system (Pinnacle, Phillips Medicals). To limit dose streaking effects outside of the PTV, we imposed the optimization constraints to the surrounding normal tissue extending from PTV with ~1 cm margin to the skin surface. Dose volume histograms (DVH) of 6-MV and 18-MV plans were analyzed. **Results:** The DVH curves for PTV, GTV, rectum and bladder were found to be nearly indistinguishable between 6-MV and 18-MV treatment plans. The dose hot spots were marginally lower (0-2%) for the 6-MV plans. The integral dose to the surrounding normal tissue was slightly (< 1% - 10%) higher for the 6-MV plans. Considering the large volume of the surrounding normal tissue, such small difference suggested that the low entrance dose from the 18-MV beam is mostly balanced out by the higher exit dose of the beam. **Conclusion:** Intensity modulated beams of 6 MV are equivalent to 18 MV for large prostate patient treatments.

SU-FF-T-74

Effects of Patient Positioning and Treatment Techniques On the Potential for Dose Escalation in Patients with Gynecological Malignancies with Para-Aortic Lymph Node Involvement

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Purpose: To investigate the effect of patient positioning and treatment technique on the potential for dose escalation in pelvic and para-aortic irradiation. **Method and Materials:** 5 patients with gynecological malignancies were CT-scanned in prone, with belly-board, and supine positions. For each patient and position 3D and IMRT plans were generated to 45 Gy. The CTV encompassed the pelvis and para-aortic nodes. PTV was a 3D, 0.6 cm expansion. We contoured kidneys, spine, small bowel, bladder and rectum, and compared the doses distributions. Dose conformity was assessed using the conformity index $CI = V_{T,P} / V_P$, where $V_{T,P}$ is the target volume receiving prescription dose or greater, and V_P is the volume receiving the prescription dose. For organs at risk we compared mean (e.g. for kidneys) or maximum (e.g. for spine) doses. **Results:** Target conformity was significantly improved for IMRT plans as compared to 3D plans. IMRT plans, regardless of position, resulted in superior sparing of spine and bowel compared to 3D plans . For IMRT we found no significant difference in bowel doses between supine and prone belly-board positions. The kidneys received lower doses in the 3D plans, but IMRT doses were much lower than tolerance. Contrary to small field irradiation, the integral dose in these large-field IMRT plans was not more than in the 3D plans. **Conclusion:** IMRT has the potential to allow dose escalation in whole pelvic and para-aortic radiation as compared to 3D plans, with increased sparing of critical organs. For IMRT, *regardless* of patient positioning, there is no significant difference in doses to either targets or critical structures. Thus, for reasons of setup reproducibility and patient comfort, supine IMRT would appear to be the better choice. The problem of organ motion in the irradiated area must be addressed before IMRT can be implemented.

SU-FF-T-75

IG IMRT of Tumors On Convex Surfaces with Grazing Incidence Photon Therapy

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Purpose: The treatment of tumors on convex surfaces with a uniform dose is a challenging problem in radiotherapy. Traditionally, surface tumors have been treated with electron beams or a combination of electron and photon beams with consequent problems of uniformity at regions of abutment. Grazing Incidence Photon Therapy (GIPT) can potentially provide better dose uniformity and tissue sparring than current standards of care but is typically more complex and requires exacting set-up conditions. The advent of image guided (IG) intensity modulated radiation therapy (IMRT) provides a new opportunity to explore potential of this method for the treatment of tumors on convex surfaces. The treatment of the total scalp with GIPT is an ideal test of the potential of IGIMRT because the beams are grazing incidence throughout the treatment volume and a sensitive structure is in close and constant proximity. **Method and Materials:** Helical tomotherapy plans using GIPT were developed for the Rando phantom and a patient for the treatment of the total scalp. A patient plan

using the Lateral Photon Electron (LPE) technique was developed for comparison. TLD measurements were made with Rando for dose verification in addition to dosimetry quality assurance. **Results:** The Rando plan and dosimerty demonstrate that the IMRT method using GIPT provides a clinically acceptable treatment. The patient plan shows a reduction in scalp dose non-uniformity by 34% and improved sparing of peripheral brain by a reduction of the volume exposed to ≥40 Gy to 17% of the LPE method. **Conclusion:** GIBT of the total scalp is clinically feasible when implemented with IGIMRT. It substantially improves the quality of patient care when compared to current standards of care by resolving the issue of abutting fields. This has broad implications for the treatment of tumors on convex surfaces by IGIMRT.

SU-FF-T-76

Implementation and Initial Testing of a Monte Carlo Based Algorithm for IMRT Inverse Treatment Planning

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Purpose: To report on the implementation of a Monte Carlo (MC) based algorithm and to compare this system with a convolution/superposition-based algorithm (CS) for IMRT inverse planning. **Method and Materials:** The DPM MC code was modified using a fluence matrix approach to perform beamlet calculations for IMRT planning. The code was integrated within our in-house inverse treatment planning system and compared with the TPS (CS) algorithm. Initial testing involved the computation of 6 MV beamlet depth doses for 1x1, 2x2 and 10x10 (100, 1 cm beamlets) in a water phantom. MC and CS calculations were then performed for an example lung treatment plan to examine dosimetric differences between these algorithms. MC statistical uncertainties were on average less than 2% (in the depth doses) for all beamlet calculations. Optimization of beamlet doses is carried out using simulated annealing with quadratic cost functions derived from our clinical protocols. **Results:** Beamlet depth doses calculated with MC and CS are in good absolute agreement for field sizes larger than 2x2 cm^2. Significant differences exist for 1x1 beamlets because CS is unable to accurately model lateral electron transport. For the example lung plan, much smaller differences were found. This is likely due to the fact that with larger field sizes (~10x10 cm in the example), effects of lateral electron scattering are much less pronounced. **Conclusion:** We have implemented a fluence matrix method to perform MC-based beamlet calculations for IMRT planning. Initial testing for an example lung plan and field sizes larger than 2x2, revealed good agreement between MC and CS. However, larger differences were found for 1x1 beamlets due to lateral electron transport issues. Testing is currently being performed for a variety of treatment plans, spanning a range of field sizes to thoroughly investigate dosimetric differences between MC and CS in IMRT planning.

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SU-FF-T-77

IMRT of Superficial Tumors

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Purpose: Due to inadequate beam modeling in the buildup region, large differences exist between planned and delivered IMRT doses for superficial targets. Our measurements show that plans underestimate doses delivered to superficial target regions by upto 40%. This results in unexpected skin reactions in patients and overdosing of critical structures. In this work, surface dose for such cases was investigated. **Method and Materials:** Using Rando phantom, IMRT plans were developed for PTVs located at: (1) skin surface (PTV0); (2) 10mm from skin (PTV10), and (3) phantom center (PTVctr). Dose distributions in Rando phantom were measured with EDR films and verified by MOSFET detectors. QA for all IMRT plans was done in a cube phantom using EDR films and ion chamber. **Results:** For PTV0, measurements in Rando phantom showed surface receiving full dose. In contrast, planned surface dose was 40% lower. In fact, superficial regions (up to 7mm) of PTV were underdosed. In distal target regions, agreement between planned and measured doses was good. For PTV10, agreement between planned and delivered surface doses was significantly better (~10%). MOSFET measurements indicated 42.5% and 8.5% surface overdose(average) for PTV0 and PTV10 respectively. For centrally located tumors, measured and planned doses were in excellent agreement. In QA phantom, dose uniformity of transferred targets depended on their location. For PTV0, the side of the tumor that was facing surface received 30% higher dose than prescription. For PTV10, dose increase was 10%. **Conclusion:** In IMRT plans, adequate target dose is delivered without bolus. Extreme care must be exercised in delineating superficial PTVs. Whenever possible, a minimum distance of 1cm between skin surface and PTV must be preserved. With smaller distances, the skin may appear to be erroneously spared. This phenomenon is not detected by commonly used IMRT QA procedures. Therefore, in-vivo measurements are recommended.

SU-FF-T-78

IMRT Treatment Planning for Mantle Fields

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Purpose: To develop a method for Mantle field IMRT treatment planning using commercially available equipment. **Method and Materials:** In this study all plans were created for a Siemens Primus linear accelerator on a Philips Pinnacle Treatment Planning System. A crucial feature of the treatment planning system was the capability to create dose-based regions of interest (ROIs). The Siemens accelerator was chosen for its ability to deliver treatments using magna fields without field-splitting. Patients were CT scanned and the data transferred to the planning system. Traditional mantle fields, including 50% transmission lung blocks, were drawn on the AP/PA digitally reconstructed radiographs. An initial plan with equally weighted AP/PA beams was set up with a homogeneous calculation to a point at mid separation. The 50% isodose curve of the resultant distribution was contoured and converted to a physical target volume. The isodose representing the involved lungs under the partial transmission blocks was also contoured and converted to a second ROI target. The lungs were manually outlined as critical structures. An IMRT plan with DVH-based target objectives was performed and compared with a protocol-based 3D conformal plan. **Results:** Creation of ROIs using dose contouring was determined to be straightforward and reliable. IMRT optimization using the ensuing ROIs was found to be reproducible and robust. For the case study presented, the 3D plan showed a 37.0% decrease in the ICRU defined conformity index for 100% of the prescribed target dose and an undesirable 63.5% increase in the volume of lung receiving 80% of the prescribed dose. **Conclusion:** IMRT mantle treatment planning can easily be performed in under an hour using commercially available equipment. Unlike the traditional approach with no defined target, this procedure allows for quantitative plan evaluation using both isodose distributions and dose volume histograms.

SU-FF-T-79

IMRT with MLC Rotation – Dose Volume Benefits of High Precision Treatment Planning

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Purpose: To evaluate a new method of treatment planning that incorporates collimator rotation into MLC based fluence segmentation. **Method and Materials:** A set of treatment plans were generated using a new technique for fluence segmentation where the collimator is rotated in between each MLC sub-field. It was previously shown that this technique has improved spatial resolution, increased flexibility in generating aperture shapes and decreased systematic error due to interleaf effects. Unfortunately these studies were limited to single fields. In this study we evaluate the ability of the rotating collimator technique to generate conformal dose distributions by comparing to conventional IMRT plans. Plans for a simple geometric phantom as well as a prostate and nasopharynx carcinoma recurrence were generated. One set of plans was generated with a conventional step-and-shoot delivery method (no MLC rotation) while a second set was generated with the collimator rotation segmentation method. **Results:** 3D dose comparisons as well as DVH analyses show that target coverage is equivalent or better with collimator rotation. Healthy tissue sparing is improved with collimator rotation, although more so for the smaller, more complex, nasopharynx target. It is also shown that increasing radiation efficiency (decreasing monitor units) will increase healthy tissue sparing. A decrease in the number of monitor units is seen with collimator rotation for both clinical cases. **Conclusion:** By incorporating MLC rotation into IMRT planning it is possible to

improve target conformity and healthy tissue sparing. These benefits are more significant for smaller targets of higher complexity. The number of monitor units will also decrease, providing less transmission and total body scatter dose. **Conflict of Interest:** This work was supported in part by Varian Medical Systems.

SU-FF-T-80

Incorporation of Isodose-Level Control to a Simplified Intensity-Modulated Radiation Therapy (sIMRT) Technique for Whole Breast Radiotherapy

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Purpose: To incorporate isodose-level control in a simplified intensity-modulated radiation therapy (sIMRT) technique (*Med. Phys.* **29**, 522-529, 2002) for radiotherapy of large intact breast. **Method and Materials:** The parallel-opposed tangential beam configuration has been used in many implementations of intensity-modulated radiation therapy (IMRT) for large breast because of the dose constraints of contralateral breast and lung and the geographical constraint of breast target volume. For this beam configuration, a simplified IMRT (sIMRT) technique (*Med. Phys.* **29**, 522-529, 2002), based on delivering equal prescription dose to the mid-point of breast tissue seen by each pair of beamlets of intensity-modulated 6 MV beams, provides efficient and robust IMRT planning. However, hot spots greater than 10% still exist near the base in the medial and lateral aspects of breast when the irradiated tissue in the beamlet path is greater than 20 cm. These beamlet paths often include part of ipsilateral lung and rib cage, to which the dose should be reduced. Modifications to the sIMRT algorithm were made so that dose to lung and consequently the hot spots in the medial and lateral aspects of breast can be reduced. **Results:** An automated algorithm, which delivers prescription dose to tissues near the lung-breast tissue interface and to the mid-point of the breast tissue, and a manual user-definable isodose-level control algorithm were developed and tested. Incorporation of these algorithms in sIMRT yielded lower dose to lung with smaller medial and lateral hot spots, in addition to the reduction of hot spots in the superior and inferior aspect of breast. **Conclusion:** sIMRT with isodose-level control at the lung-breast tissue interface near the base of large breast can be used efficiently for whole breast radiotherapy using the parallel-opposed tangential beam setup.

SU-FF-T-81

Mixed Beam Energy for IMRT Treatment of Prostate Carcinoma

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Purpose: To investigate the technical and dosimetric properties of IMRT plans for prostate carcinoma using standard beam orientations with mixed beam energies. **Method and Materials:** A cohort of 10 patients previously treated with IMRT for prostate carcinoma was selected. For each patient, three additional IMRT plans were calculated using a standard coplanar 5-beam arrangement and compared to the delivered treatment plan. All plans used 6 MV for the anterior oblique fields and the posterior field, while the two posterior oblique fields were either 10, 15, or 18 MV. An identical set of constraints was used for the PTV and organs at risk (rectum and bladder) and all plans were normalized to give 95% PTV coverage at 100% of the prescription dose. Competing plans were analyzed based on DVH, conformity index, total body integral dose (photon and neutron), and the total and compartmentalized number of MU. **Results:** Equivalent conformity of dose to the PTV was achieved in all plans. The photon integral dose and number of MU, however, were significantly higher for plans with only 6 MV beams, while the 6/18 MV combination resulted in the lowest value for each of these parameters. For the 6/15 and 6/18 MV plans, the number of MU to be delivered with the pair of higher energy beams was found to be comparable to the number of MU delivered in a standard 4- or 6-field 3DCRT beam arrangement. **Conclusion:** While the neutron integral dose rapidly increases beyond 10 MV, its magnitude in a mixed beam energy plan has been shown to be comparable to the neutron dose encountered in 3DCRT for prostate carcinoma. The resulting decrease in photon integral dose achieved in IMRT plans with mixed beam energies may thus suggest the selection of higher energy for those beams requiring the greatest tissue penetration.

SU-FF-T-82

Non-Tumor Integral Dose in Conformal, External Beam Radiation Therapy

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Purpose: To investigate the computed non-tumor integral dose (NTID) delivered during treatment of prostate cancer with intensity modulated radiotherapy (IMRT) compared to three-dimensional conformal radiotherapy (3DCRT). Low and high-energy photon treatments were also evaluated in this study, as was helical tomotherapy for IMRT delivery versus a conventional linac. **Method and Materials:** Five patients with localized prostate cancer were selected. Five treatment plans were generated for each, including: IMRT with both 6 and 20 MV photons using a conventional linac (6MV-IMRT, 20MV-IMRT respectively), 3DCRT with both 6 and 20 MV photons (6MV-3DCRT, 20MV-3DCRT respectively), and IMRT with 6 MV photons delivered using helical tomotherapy (Tomo-IMRT). For each plan, a total of 70 Gy was prescribed to 95% of the PTV and the integral dose was calculated from dose-volume histograms for non-tumor tissue as well as surrounding critical structures. **Results:** The NTID with conventional IMRT was 3.9-5.2% less than with 3DCRT, and the use of 20 MV photons resulted in 6.7-8.0% less NTID than treatments using 6 MV. Tomo-IMRT treatments were comparable to those delivered with a conventional linac. Examination of the integral dose given to surrounding critical structures showed that, compared with 6MV-3DCRT, 6MV-IMRT reduced the integral doses to the rectal wall and penile bulb by 2.8% and 6.3% respectively. Tomo-IMRT further reduced the integral doses to these structures by 12.6% and 18.0% respectively. No reductions were seen using 20 MV. **Conclusion:** The differences in NTID calculated from different treatment plans are relatively small and might be negligible after accounting for leakage and neutron production at higher energies. The advantage of helical tomotherapy in the treatment of localized prostate cancer was demonstrated through the greater sparing of critical structures with no significant increase in NTID. **Conflict of Interest:** This work was partially supported by TomoTherapy Inc. and PO1 Grant CA88960-01-05.

SU-FF-T-83

Partial Breast Treatment Using Energy- and Intensity- Modulated Photon and Electron Beams

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Purpose: A new treatment technique has been developed for partial breast treatment using energy- and intensity-modulated photon and electron beams. Treatment plans for partial breast irradiation using this technique are investigated in this work. **Method and Materials:** Two tangential photon beams with several electron beams of different energies and field shapes were used for partial breast irradiation. The patient setup and the orientations of the two opposed tangential photon beams were the same as conventional treatment for the whole breast. The electron beams were perpendicular to the patient skin surface. The dose-distributions for the photon beamlets and electron apertures were calculated by a Monte Carlo code, EGS4/MCSIM. The optimization was performed based on the Monte Carlo dose distributions employing a gradient search method. The photon beams were delivered using a multi-leaf collimator with a step-and-shot technique and the electron beams were delivered using cutouts. The effects of bremsstrahlung leakage and electron scattering by the cutout were taken into account in the Monte Carlo simulations. **Results:** Treatment plans using this new technique for five breast patients were generated for partial breast treatment. Compared with multi-field photon IMRT, this new technique required no change for patient setup from the conventional technique and resulted in less dose to the ipsilateral lung and other normal tissues and less dose to the contralateral breast. Our results showed that the dose to the contralateral breast was reduced by about 50%. The volumes of normal tissues exposed to high and moderate radiation dose were reduced up to 50%. The doses to critical structures, such as the lung and the heart, were also reduced significantly. **Conclusion:** The new treatment technique integrates intensity- and energy-modulated photon and electron beams and combines the advantages from both treatment modalities for partial breast treatment.

SU-FF-T-84

Preferential Non-Uniform Target Dose Distribution Using IMRT and PET/CT Imaging- a Feasibility Study

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Purpose: To investigate the feasibility of planning non-uniform dose distribution based on FDG PET uptake within target and its impact on normal tissue structures using IMRT. **Method and Materials:** An IMRT treatment planning study was performed on a patient with colon metastasized liver cancer to investigate the effect of the non-uniform target dose on the normal structures. Tumor and normal tissue such as liver, right kidney and cord were outlined on the CT scans registered with PET images. Two IMRT plans were generated for evaluation. In plan A, tumor was prescribed uniform dose of 50 Gy. In plan B, dose to the tumor periphery that showed mean SUV uptake four times the tumor core was increased to 100 Gy. Normal liver dose constrain was set such that 30% of the liver receives less than 30 Gy. The maximum spinal cord and right kidney doses were constrained to 45, and 30 Gy respectively, in both plans. **Results:** Plan A met the prescribed dose constrains with six beams. Dose to tumor was within 5% of the prescribed dose. However, the number of beams had to be increased to nine to meet the dose constrains in plan B. In this plan while 30% of the normal liver was still receiving less than 30 Gy, dose to 50% of liver was increase from 10 Gy to 20 Gy. Also, maximum spinal cord that was 20 Gy in plan B, was increased to 40 Gy in plan B. The right kidney doses were virtually unchanged in both plans. Although partial doses to liver and spinal cord were increased in plan B but they were still below the tolerances for these organs. **Conclusion:** This study showed that in this particular case dose to biologically active tumor subregion could be increased considerably without exceeding normal tissue tolerances.

SU-FF-T-85

Radiation Induced Cancer After Radiotherapy: The Impact of IMRT and Proton Radiotherapy

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Purpose: There is concern about the increase of radiation induced malignancies with the application of modern radiotherapy treatment techniques such as IMRT and proton radiotherapy. In this work we analyze not only x-ray scatter and neutron radiation , but also the impact of the primary dose distribution on secondary cancer incidence. **Method and Materials:** The organ equivalent dose (OED) concept with a linear-exponential dose-response curve was applied to 3D dose distributions of 30 patients who received radiotherapy treatment of prostate cancer. From the 30 patients 11 received 3D conformal radiotherapy, 11 IMRT with 6MV photons and 8 spot scanned proton radiotherapy. The IMRT treatment plans were re-calculated with 15 MV photons. For 18 MV photons the OED was approximately calculated. From the OED of the different treatment techniques secondary cancer risk was estimated. **Results:** IMRT prostate treatments using low energies result in a modest increase of around 15% of radiation induced cancer compared to conventional four field planning with 15 MV photons. Using energies larger than 10 MV for IMRT could increase the probability to develop a secondary cancer by more than 20% (15MV) and 60% (18MV). The use spot scanned protons for treatment can reduce the secondary cancer incidence significantly by about 50%. **Conclusion:** By including the primary dose distribution into the analysis of radiation induced cancer incidence the resulting increase in risk for secondary cancer using modern treatment techniques such as IMRT is not as dramatic as expected from earlier studies. By using an energy of 6 MV only a moderate risk increase can be expected. Spot scanned protons are the treatment of choice in regard to secondary cancer incidence.

SU-FF-T-86

Rapid (<15 Minutes) Automated Tangential Breast IMRT Treatment Planning With Cutplane Evaluation

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Purpose: To develop an automated, dose-based IMRT planning technique for tangential breast irradiation and to introduce a novel technique for efficient plan evaluation in three-dimensions. **Method and Materials:** Patients were CT-simulated using an isocentric SAD technique with the medial and lateral tangents designed to encompass the breast tissue. The CT data and the beam information were transferred to the treatment planning system (TPS). The dose was then calculated for standard open equally weighted split beams. The planar dose rate matrix for a beams-eye-view plane was calculated and exported to a PC. An in-house program was developed to rescale this matrix and automatically create a series of dose-based MLC segments. Creation of the MLC segments took less than a minute. The MLC segments were imported back into the TPS where utilities were used to determine the optimal segment weights. An efficient plan evaluation tool was developed that presented the dose distributions in only three or less cutplanes parallel to the plane formed by the posterior beam border. The mathematical formalism for determining the cutplane orientation will be demonstrated. The planning and evaluation tools were tested on three representative case studies and compared to wedged tangent plans. To ensure unbiased comparison all plans were normalized to identical ICRU Reference Points. **Results:** The entire planning process, from CT import to plan completion, took approximately 15 minutes. For all cases studied the IMRT plans demonstrated superior coverage and dose homogeneity as determined by both isodose coverage and the ICRU Conformity Index. Cutplanes through the lung, mid breast, and apex were found to be the most clinically useful. **Conclusion:** The automated procedure is able to consistently produce optimized IMRT breast treatment plans within a few minutes. Isodose distributions in three cutplanes parallel to the posterior border are an effective tool for rapid plan evaluation.

SU-FF-T-87

Software Tools for Transferring Treatment Plans Between Two Planning Systems

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Purpose: There is often a need to transfer treatment plan data from one system to another. However, even when both systems are claimed to be compliant with a standard (e.g., DICOM-RT), the system-specific implementations may be incompatible . The purpose of this work is to develop and evaluate tools to seamlessly transfer plans designed on one commercial treatment planning system (TPS) to another TPS and vice versa. **Method and materials:** Pinnacle and Eclipse are the two TPS used in this study. From Pinnacle to Eclipse, a filter to make the Pinnacle DICOM-RT plans conform to Eclipse implementation was developed. From Eclipse to Pinnacle, a tool to covert a DICOM-RT plan file to Pinnacle Script file was developed. To evaluate these tools, ten prostate patients planned and treated using IMRT at our institution were used. The 10 IMRT plans were first transferred from Pinnacle to Eclipse, and the doses of the 10 plans were recalculated on Eclipse. New IMRT plans were designed on Eclipse also. The latter were transferred back to Pinnacle and doses were re-calculated there. Also, optimal fluence distributions generated on Eclipse were transferred to Pinnacle, and the Pinnacle's leaf sequencer was used to generate new leaf sequences. To evaluate the differences between Pinnacle and Eclipse plans, dose and dose-volume indices were used. **Results:** The dosimetric data for the plans transferred to Eclipse from Pinnacle do not differ significantly from the original plans, and vice versa. For plans of similar quality, the ones designed on Eclipse had 56% fewer segments than the plans designed on Pinnacle. The Pinnacle generated 23% more segments than the Eclipse using the same optimized fluence distributions imported from Eclipse.
Conclusions: DICOM-RT implementations are often not complete and, therefore, compatible among different commercial planning systems. Special tools are needed to make the plans interchangeable.

SU-FF-T-88

Study of Merits On IMRT with Gating Technique for Treatment of Intrahepatic Cancer

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Purpose: To investigate and compare the benefits in terms of dose escalation, increases of TCP, decreases of NTCP and increases of dose conformity of four various techniques, i.e., 3DCRT and IMRT with and without gating techniques respectively, for treatments of intrahepatic malignancies. **Method and Materials:** Total 9 patients with liver cancer

went through this study. Every patient has four set of plans, i.e., 3D conformal with and without gating, and IMRT with and without gating. Plans of different techniques were then evaluated with the following elaborated approaches: Kutcher's effective volume, Lyman's NTCP for the normal liver, and the Ten Haken's TCP for the intrahepatic cancer. **Results:** To keep a maximum of 5% NTCP of the normal liver for each technique and assume 3DCRT technique without gating as our norm for comparison. The 3DCRT combined with gating technique would increase 4.5Gy more in total target dose and 4.5% higher in TCP of liver lesion. Furthermore, 12 Gy and 6 Gy more in the total target dose and 13% and 8% higher in TCP of liver lesion were found with the IMRT technique with and without gating respectively. **Conclusion:** After reviewing and analyzing these various techniques, the combined technology of IMRT and gating seems to be right approach for treatment of liver lesion. IMRT with gating technique may have the most advantages in reducing the treatment margins, increasing the dose conformity, allowing us to escalate total target dose and improving tumor control probability simultaneously.

SU-FF-T-89

The Effect of Breast Motion On Dose Distribution in Tangential IMRT with Direct Aperture Optimization

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Purpose: Inverse planning for breast IMRT can be accomplished with Direct Aperture Optimization (DAO) where the user defines the traditional tangential fields within which the shapes and weights of multiple segments, including an open segment as 'flash', are optimized. The purpose of this study is to evaluate the technique and examine the effects of relative weights of the open segments to other segments on the impact of breathing motion. **Method and Materials:** IMRT plans were generated using DAO inverse planning with manually fixed relative weights of the open segments. To simulate breathing motion, the same set of optimized segments was reapplied with the isocenter shifted up and down by up to 1cm and the resulting dose distributions were added. The quality of both the static plans and the composite plans were compared among different open segment weights. **Results:** Five cases with varying breast sizes were examined. For the static plans, we found that uniform dose distributions could be generated with relative weights of the open segments in the range of 45-85%. Unacceptable hot spots were produced when the weights of the open segments were larger than 85%. For composite plans simulating breathing motion, the most uniform dose distribution happens when the open segment weights were in the range of 75-85%, below which the dose uniformity degrades. We observed that in the composite plans, for each 1% decrease in the open segment weighting, the volume covered by the 98% dose decreased by approximately 0.06%, independent of breast size. **Conclusion:** DAO provides a robust and efficient technique for breast IMRT planning. The proper open segment weight was found to be between 75% and 85%, and is not significantly dependent of breast size and laterality. Within this range, high-quality IMRT plans were produced for each case.

SU-FF-T-90

The Use of Bluetooth Technology in Multiple Monitoring of Vital Signs – ECG and Pulse

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Purpose: The aim of this work is to evaluate the strengths and demonstrate the benefit of using Bluetooth wireless technology in medical equipment, for close monitoring of multiple patients with heart problems (ECG and vital signs) in recuperatory stage. The main issue discussed and tested is whether Bluetooth technology is ready to be implemented and used to realize an environment were computers would assist the medical staff in offering solutions and real time response, based on the data received from patients, in critical situations. **Method and Materials:** Our preliminary work consists in a simulation soft (VC++) for monitoring two patients (ECG and pulse), with two Bluetooth equipped devices. Bluetooth is a rather new low-cost radio technology which operates in the free, unlicensed 2.4 – 2.4835 GHz ISM (Industrial, Scientific, Medical) band, and is designed to unite or connect all different types of devices to effectively work as one. The soft created is a server-client based program that interact through information messages interpreted as graphs and action instructions. **Results:** The server receives instantaneously the data sent by the patients and after a process of comparing, in which if the data for Pulse or ECG is higher or lower than some user-specified values, it builds dynamic charts for the two patients.
We assumed the following limits both for ECG and Pulse: lower=50 and upper=130. A counter holds the number of times these values were crossed (under/over), and at 5 or more the application is stopped, and pre-defined messages will appear on the server and patient interfaces. **Conclusion:** The tests performed presented a very good response of the system – real time – thus giving us a very good reason to think that this technology could be used to perform hard tasks and intervene much more accurate than human personnel can.

SU-FF-T-91

Unusually Large Fluctuation of Monitor Unit (MU) Efficiency in Large-Field IMRT Plans Using Sliding-Window Technique

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Purpose: To examine the Monitor Unit (MU) efficiency (prescription dose in cGy as a percentage of the total MU) of large-field IMRT using sliding-window and step-and-shoot techniques and their implication to patient whole-body dose. **Method and Materials:** Seven large-field IMRT plans for pelvic/abdominal cancers were generated on the Eclipse treatment planning system using 18 MV photon beams. The MU efficiency of each plan was calculated for both the sliding window and the step-and-shoot (with 15 intensity levels) techniques for a 120-leaf multileaf collimator on a Varian 2100CD linear accelerator. The impact on patient whole-body dose resulted from accelerator leakage was estimated from the ratio of total treatment MUs of the two techniques. **Results:** The MU efficiency for large-field IMRT using either sliding-window or step-and-shoot technique (< 20%) is lower than that of medium-field-size prostate plans (~30%). As expected, the MU efficiency of step-and-shoot technique is better than that of sliding window for all seven plans. However, unusually large fluctuation of MU efficiency (to as low as 5.5%) was observed among the plans using sliding-window technique. In the extreme case, the use of step-and-shoot resulted in a 130% increase in MU efficiency over sliding-window as opposed to the typical increase of 10 – 30%. The implication on patient whole-body dose is enormous as the total MU needed to deliver 70 Gy would be 127,000 for sliding-window and only about 55,000 for step-and-shoot. In this case, the whole-body dose due to leakage x-ray and neutrons is reduced by a factor of 2.3 using step-and-shoot technique instead of sliding-window. **Conclusion:** The MU efficiency for large-field IMRT is low and large MU is usually required to deliver a given prescription dose. Since step-and-shoot technique yields consistently better MU efficiency than that of sliding-window, it should be used for large-field IMRT delivery.

SU-FF-T-92

Volumetric Breast IMRT Planning Using ICRU-50 Concepts

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Purpose: In this study we present a method of performing volumetric breast IMRT using ICRU 50 concepts of CTV and PTV while respecting the irradiated volumes of conventional breast tangents. **Method and Materials:** The technique uses standard tangential beam directions. Conventional tangents are placed on the patient's planning data and are used as a guide. Breast tissue, defined by clinical palpation and CT, is contoured as the CTV. The PTV is created by expanding the CTV 0.7 cm in the medial and posterior direction to account for setup error and breathing motion. The PTV and CTV are kept to within 0.5 cm of the skin surface, and 0.6 cm of the conventional beam edges to allow for penumbra and buildup. In the superior and inferior directions the PTV may be extended to cover traditional margins. Anteriorly, the IMRT field pattern is extended 1.5 cm from the PTV into air for setup error and breathing motion. **Results:** Twenty patient plans were reviewed comparing conventional and IMRT CTV doses. The plans used both 6 and 10 MV. Analysis showed comparable coverage (V95) to the CTV with a reduction in the volume receiving higher dose using IMRT. The average percent difference to V95 was 0.6%. With IMRT the average reduction to V105 was 19.5%, and there was an average reduction of 1.72 Gy to the hottest

1% of breast tissue. **Conclusion:** The margins used in conventional breast treatment have been the standard of care for many years. Volumetric IMRT breast planning offers superior dosimetric results but defining the volumes can be a challenge. This technique allows the creation of the IMRT targets while preserving coverage of similar margins used in conventional treatment. This technique is currently used clinically at our institution.

SU-FF-T-93

A Clinical Comparison of Two IMRT Planning Systems for Small Field Conformal Therapy of Intracranial Lesions

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Purpose: To evaluate BrainLab (BL) IMRT dose distributions for small intracranial lesions by comparing target dose coverage, homogeneity and conformity, and critical structures sparing, as well as agreement with measurements to a clinical Eclipse IMRT system. Method and Materials: Three clinical cases with varying volume lesions enclosing portions of organs at risk (OAR) were planned with BL and Eclipse IMRT modules for dynamic 120-leaf MLC delivery on a Varian 21EX. Anatomical structures were contoured, and transferred to both systems to ensure a common starting point. Optimization was carried out using identical non-coplanar beam orientations in combination with similarly specified dose goals and constraints. For two of the cases, highest priority was placed on PTV coverage, while the third required OAR sparing at the expense of PTV coverage. Plans were evaluated by dose-volume histograms (maximum dose, conformity indices), and isodose lines (hot spots, 50% isodose volume irregularity). BL dose distributions were validated with chamber (absolute dose) and film (fluence) measurements, and Eclipse dose calculations for imported BL dynamic MLC files. Results: Ignoring the superior immobilization of the BL system for patient set-up, BL and Eclipse IMRT modules provided clinically comparable target coverage and dose homogeneity, with differences in target dose conformity, critical structures sparing, and agreement with measurements. BL plans showed better dose homogeneity up to 5% for the smaller tumors, conformity up to 25% for the larger tumors, and consistently better critical structures sparing up to 11%. Absolute dose measurements were in closer agreement for the BL plans, while selected line profiles through the fluences revealed departures from experiment in the low dose penumbra region for BL plans and high dose/high gradient regions for Eclipse plans. Conclusion: BL and Eclipse IMRT modules generate effective treatment plans with differences requiring further investigation, including determination of their clinical significance.

SU-FF-T-94

Clinical Evaluation of Direct Machine Parameter Optimization Algorithm for Head and Neck IMRT Treatment

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Purpose: Because many critical structures are in close proximity to target volumes, cancers of the head and neck (H&N) are often suited for treatment with IMRT. However, the time required to generate and deliver a clinically acceptable IMRT plan can be significantly longer than a conventional plan. This study evaluated a new inverse planning algorithm, DMPO (direct machine parameter optimization), with attention to parameter settings, plan quality and treatment efficiency for H&N cancers. **Method and Materials:** The Pinnacle treatment planning system version 7.4 was used. The DMPO allows users to limit the number of total MLC segments (N) for treatment. After a user-defined number of iterations (*n*) for pencil beam optimization, the DMPO generates MLC segments for each field for dose calculations using a convolution algorithm. Both the MLC leaf positions and the weight of each segment are then optimized until cost tolerance or iteration number is reached. Treatment plans generated using DMPO were compared with H&N cases that were previously treated using an older version (6.2). The plan quality was compared using cost functions and DVHs of target volumes and critical structures. The total monitor units and MLC segments for treatment were compared for different combinations of *n* and N. **Results:** The DMPO provided plans of DVHs similar to clinical cases with significantly less planning time. More importantly, the total MU and MLC segments for treatment delivery were reduced by 40% to 50%. Cost functions changed only slightly on *n* and N and total MU increased as *n* increased, but was independent of N. Our preliminary data indicated a combination of *n*=10-15 with 10 segments per field appeared to be optimal for most H&N cases. **Conclusion:** The DMPO algorithm generated more efficient plans while providing equal or better quality than the previous plans for IMRT treatment.

SU-FF-T-95

Dosimetric Comparison of Helical TomoTherapy Treatment and Step-And-Shoot Intensity-Modulated Radiotherapy Treatment On Stereotactic Radiosurgery

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Purpose: To evaluate the feasibility of Helical TomoTherapy for stereotactic radiosurgery, and to compare the dose conformity, dose uniformity, and dose gradient between plans of Helical TomoTherapy and step-and-shoot intensity-modulated radiotherapy (IMRT) generated by the NOMOS CORVUS system.. **Method and Materials:** Thirteen patients with intracranial tumors treated with stereotactic radiosurgery by step-and-shoot IMRT were analyzed. Tumor sizes varied from 1.45 cc to 40.78 cc. Two step-and-shoot IMRT treatment plans, one (IMRT I) with gantry angle restriction due to the existence of beam stopper at our institute and the other (IMRT II) with those constraints removed, were generated using the CORVUS system. Helical TomoTherapy treatment plans were generated for each case with identical anatomic contouring and prescription. The three plans were compared using dose conformity index, homogeneity index and dose gradient score index. **Results:** IMRT II plans without field angle constraints resulted in better dose conformity and steeper dose drop-off outside the targets compared to IMRT I with beam stopper restriction. Statistical analysis showed that TomoTherapy plans were better compared to the two step-and-shoot IMRT plans by dosimetric study. The average dose conformity index for TomoTherapy is 1.33 (range: 1.14 – 1.60). For IMRT II plans, it is 1.39 (range: 1.17 – 1.89). The dose gradient score index, with 100 being optimal, is 37.3 (range: 16.5 – 52.7) for TomoTherapy plans, and 18.9 (range: –31.1 – 36.2) for IMRT II. Dose homogeneity index does not show statistical difference for the three treatment plans. The average treatment time for TomoTherapy plans is 47 minutes. **Conclusion:** TomoTherapy treatment planning showed significantly better results compared to the step-and-shoot IMRT treatment planning in dose conformity and dose gradient for intracranial stereotactic radiosurgery. The treatment time using TomoTherapy was comparable to that using step-and-shoot IMRT. **Conflict of Interest:** Research partially supported by TomoTherapy Incorporated.

SU-FF-T-96

Improvement in IMRT Delivery for Head and Neck Patients Using Simplified IMRT Plans and Enhanced IMRT Delivery System

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Purpose: To demonstrate the feasibility of simplified IMRT plans and improved delivery times without significantly degraded plan quality. **Method and Materials:** Five patients with nasopharynx tumors were selected for evaluation. The plan quality was assessed based on tumor coverage, multiple defined endpoints for sensitive structures, plan dose conformality and homogeneity index. The treatment plans were generated using direct machine parameter based optimization in a commercial treatment planning system. The numbers of beam angles varied from 7-9. For each plan, the average total numbers of segments were gradually reduced from 98, 63, 48, to 24, while maintaining the planning dose constraints and number of beam angles. Treatment times are based on the latest IMRT delivery option (console 9) installed on a Siemens LINAC. **Results:** Improvements are two-fold: (1) reduction of segments and (2) technical changes within the delivery system. All plans achieved the same tumor coverage, delivering >95% of tumor volumes to 70Gy (GTV), 59.4Gy (CTV), and 54Gy (elective CTV) simultaneously. As the number of segments decreased from 98 to 24, the average maximum doses to the brainstem changed from 50,8, 50.4, 51.3, to 55.1 Gy and from 41.9, 42.2, 41.5 to 42.3 Gy to the spinal cord while the average mean parotid doses were 27.0, 26.7, 26.7, and 28.5Gy. As the total number of segments

decreased, the average plan conformal indices were 0.63, 0.61, 0.65, and 0.46, and the average dose homogeneity indices were 89%, 87%, 88%, and 84%. Optimized communication within the LINAC control system reduced the inter-segment delay from six to two seconds. **Conclusion:** For patients with nasopharyngeal tumors treated with IMRT, 50 segments might be sufficient to achieve clinical requirements. With the latest IMRT delivery system, the treatment time excluding patient setup can be reduced to 6-8 minutes. **Conflict of Interest:** Research supported by Siemens

SU-FF-T-97

A Generalized MLC Segmentation Algorithm for Step-And-Shoot IMRT with No Tongue-And-Groove Error

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Purpose: To develop an MLC segmentation algorithm for step-and-shoot IMRT that can segment intensity maps with large maximum intensity levels (e.g., ranging from 10 to 100) into the minimum number of MLC-segments in a fast computation time. **Method and Materials:** We improved a previous MLC segmentation algorithm, called SLSNOTG, for step-and-shoot IMRT by Luan et al in AAPM'2004. Our new segmentation algorithm, called GSLSNOTG, has two improvements.
(1) It can segment intensity maps with large maximum intensity levels into the minimum number of MLC-segments without tongue-and-groove error. The key to this improvement is a new level reduction technique that can partition an intensity map into an optimal set of sub-intensity-maps without introducing any additional tongue-and-groove error. In contrast, the previous SLSNOTG algorithm was mainly designed to segment intensity maps with small maximum intensity levels, and may introduce more tongue-and-groove error when segmenting intensity maps of large maximum intensity levels (due to the level reduction schemes that it uses).
(2) Our new segmentation algorithm runs much faster than the previous SLSNOTG algorithm by pruning the sizes of the graphs used to model the intensity maps. This avoids using the slower k-link shortest path routine as in the SLSNOTG algorithm, and thus significantly reduces the computation time. **Results:** Comparisons of our GSLSNOTG algorithm with the previous SLSNOTG algorithm and CORVUS 5.0 planning system demonstrated the advantages of the GSLSNOTG algorithm/software. For example, for an intensity map set of maximum intensity level 20, the GSLSNOTG algorithm computes 176 segments in less than 1.5 minutes. In comparison, CORVUS needs 382 segments, and the SLSNOTG algorithm runs in 10 minutes to compute a plan with the same number of segments with 2% tongue-and-groove error. **Conclusion:** The new MLC segmentation algorithm GSLSNOTG can segment intensity maps of large maximum intensity levels in a fast computation time.

SU-FF-T-98

A Shuttling Window Method of Improving Intrafractional Errors for Intensity Modulated Stereotactic Body Radiation Therapy

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Purpose: Intensity Modulated Stereotactic body radiation therapy (SBRT) uses multiple intensity modulated beams to deliver a large dose in limited fractions with on-board imaging/stereotactic guidance. Despite active organ motion managements such as abdomen depression or rigid frame alignment, random residual errors in the order of a few mm are still observed. In this study, we aim to develop a shuttling window delivery technique to minimize such errors. **Method and Materials:** Our method allows the MLC leaves to shuttle back and forth to accumulate the dose sequentially throughout the target volume instead of delivering a large dose to parts of the target volume. Our rationale is to avoid deleterious misfiring events from large dose depositions. A sequencing method is developed to minimize the beam-on and leaf travel for implementing the shuttle delivery. Phantom measurements were performed for simulated and patient cases. A home-made phantom was used to simulate random intrafractional errors of 0-5 mm with 0.5 mm resolution. Comparison between the prescribed dose distributions and the error-intrinsic dose distributions were carried out using chi-square confidence level analyses. **Results:** The shuttling window technique significantly reduced random dose errors and improved the agreements between the prescribed and the delivered dose distributions. As the number of the shutting cycles increases, the average dose variance decreases. The most gain for the technique was harvested when the shuttle number approaches five. Despite extra leaf motions, no significant increase in the treatment time was observed (e.g. < 1 minute for a 10-minute beam). The increase in the leaf travel distance of the shuttling delivery was largely compensated by increased leaf speed during each cycle. **Conclusion:** We demonstrated an effective approach for reducing residual intrafraction errors for intensity modulated SBRT deliveries.

SU-FF-T-99

An Analysis of Intensity Discretization Errors in IMRT

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Purpose: A simple analysis is presented of the deviation in dose when intensity is converted from continuous to discrete levels. This analysis assumes that intensity levels are equally likely and beams are discretized independently. **Method and Materials:** If there are i non-zero intensity levels possible then the standard error due to discretization for a single beam direction is just equal to:

$$\varepsilon = \frac{1}{\sqrt{12\,i}} \qquad \text{Eqn. 1}$$

There are situations in multiple beam delivery where one beam direction dominates the dose to a voxel. In this case, the accuracy that can be delivered to that voxel is going to be dependent only on the graininess of the discretization and Eqn. 1 also applies. For the case of beam direction independence, the standard error to be expected in the dose distribution for N beam directions is given by:

$$\varepsilon = \frac{1}{\sqrt{12\,i\sqrt{N}}} \qquad \text{Eqn. 2}$$

Results: For the case of 5 intensity levels, dominated by a single beam, the standard error to be expected is 5.8% according to Eqn. 1. For the case of 5 intensity levels and 5 roughly equally contributing beam directions, the standard error to be expected is about 2.2% from Eqn. 2. The standard error to be expected for a tomotherapy dose distribution with 50 intensity levels is about 0.58% when one beam direction from one rotation is dominant (using Eqn. 1). Using Eqn. 2 the standard error is 0.04% for 50 levels when beams from 51 directions and 4 rotations (i.e., pitch 0.25) contribute equally to each voxel. **Conclusion:** Equations 1 or 2 represent upper and lower limits, respectively, of the standard error due to discretization. Finer discretization and more beams reduce error, but there is more to be gained in increasing intensity levels than in increasing the number of beam directions. **Conflict of Interest:** This work was supported by TomoTherapy Inc.

SU-FF-T-100

Aperture Effects in Dynamic Fields

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Purpose: We have measured collimator and phantom scatter factors (S_c, S_p) as a function of field size for a variety of moving slit widths and compared them with static field factors. Dynamic treatment plans were devised to compare the ability of two planning systems to model the aperture effect on dose delivery, especially for small targets. **Method and Materials:** An 80 leaf Varian 2300cd and a 120 leaf Varian 21ex accelerator were used with 6 MV photons. 0.6 cm^3 ionization chambers were used, for both S_c and S_{cp} measurements. 1-10mm leaf gaps were dynamically scanned across a range of field sizes (4x4-14x40). To mimic the small aperture effect in a treatment plan, we defined a series of cylindrical targets, 1-20 mm diameter by 3cm length and an IMRT plan using Eclipse or Pinnacle^3 was developed to optimally treat them. EDR2 films were taken and used to compare delivered with planned doses. **Results:** The dynamic measurements of S_c and S_{cp} were very similar on the two Varian machines and clearly demonstrated an aperture effect in the S_c measurements of as much as 30% (1mm gap, 4x4 field) which smoothly converged to the static field distribution as the gap was increased. Derived S_p values were approximately independent of gap width, essentially matching the static field cases. Planning system intercomparison of small target doses seem to indicate the Pinnacle^3 system to be slightly better at

correctly including aperture effect. **Conclusions:** Conventionally obtained output factors, using the secondary collimators, even extended down to 1-2 cm^2 still do not describe the same head scatter contribution as is delivered by a dynamic aperture. Consequently, dose uncertainty may be amplified in the treatment of single or multiple small lesions using IMRT techniques.

SU-FF-T-101

Clinical Feasibility of "jaws-Only" IMRT Using Direct Aperture Optimization

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Purpose: To demonstrate the clinical feasibility of delivering IMRT treatment plans using only independent collimators. **Method and Materials:** The Direct Aperture Optimization (DAO) technique is used to optimize the jaw positions and the relative weights assigned to each aperture. Since all of the delivery constraints imposed by the jaws are incorporated into the optimization, the need for leaf sequencing is eliminated. This allows for "jaws-only" IMRT plans with a significantly reduced number of segments as compared with "jaws-only" plans produced with the traditional two-step IMRT approach. We applied the DAO "jaws-only" technique to three clinical cases: an abdomen, a prostate, and a head and neck. For each case, "jaws-only" DAO (JODAO) plans were produced with 5, 10, 15, 20, and 25 apertures. For comparison, a DAO plan was created that utilized an MLC (MLCDAO). The resulting JODAO and MLCDAO plans were delivered to a phantom using an Elekta Precise linear accelerator. **Results:** The results demonstrate that between 15 and 25 "jaws-only" apertures are required per beam direction to obtain conformal IMRT treatment plans that are comparable to the MLCDAO plans. The delivery times for the JODAO plans were between 15 and 20 minutes. This compares to the delivery times of 7 to 12 minutes for the MLCDAO plans. **Conclusion:** Using DAO, it is possible to create IMRT treatment plans that utilize only independent collimators. In addition, these "jaws-only" plans can be delivered in a reasonable amount of time. This can make IMRT feasible in clinics which have linear accelerators not equipped with an MLC.

SU-FF-T-102

Dosimetric Properties of Respiratory-Gated Intensity Modulated Arc Treatments

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Purpose: We investigated the dosimetric effects of gating on Intensity Modulated Arc Treatments. **Method and Materials:** One method to address respiratory motion during radiotherapy is 4DCT in conjunction with gated treatment. In the treatment of a solitary lung nodule or liver metastasis, intensity modulated arc therapy (IMAT) provides desired dose distributions. Here, we determined the dosimetric errors from delivering gated IMAT under a variety of conditions, including monitor units (MU), dose rate (MU/min), and direction of gantry rotation. We employed Varian Real Time Monitoring system for the gated delivery on a 2100C/D accelerator. To test the accuracy of the radiation delivery system, we used a static solid water phantom (IMRT phantom, MedTec). We chose a lateral 90° arc to stress test the gantry rotation delivery against gravity. Film dosimetry and point dose were performed. We delivered 30MU and 270MU treatments and used Kodak XV and EDR2 films respectively. RIT software was used to perform film dosimetry and analyses. Point doses at the isocentre were measured using a Scanditronix RK ion chamber (0.12cc). Dose distributions from gated deliveries are compared to non-gated deliveries, normalized by the dose at isocenter. Amplitude gating was used with a 25% duty cycle. **Results:** With gating, we measured ≤1.5% change in dose at the isocentre. From film dosimetry, we observed beam transverse asymmetry in the gated delivery. Dose error > 3% was measured away from the isocentre using gated IMAT when the gantry is rotating at its maximum speed (295°/min). Errors less than 3% were measured when gantry rotates at or slower than 200°/min under clinical conditions. **Conclusion:** Gate IMAT treatments yield consistent output at the isocentre but accumulate beam symmetry errors. These errors are proportional to the gantry rotational speed which can be reduced to below 3% by lowering the delivery dose rate.

SU-FF-T-103

Implementation of the Tungsten-Compensator Based Intensity-Modulated Radiotherapy (IMRT)

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Purpose: One of the methods to deliver the intensity-modulated radiotherapy (IMRT) beams is by using physical compensators. The static nature of the compensator intensity modulation shortens the treatment time, simplify the dose optimization and reduces the leakage effect from MLC-IMRT. The purpose of this project is to study the feasibility of intensity modulation by a high density material, tungsten. The commissioning process, including the packing issue and dose modeling method, are described in details, which will be helpful for other institutions to implement this technique. **Method and Materials:** The consistency of filling tungsten and durability of the compensator were tested by the repetitive filling/handling. One symmetrical and one asymmetrical step function-type compensators were manufactured for dose modeling purpose. Mapcheck device and ion chamber were used to measure the dose attenuation at different field size, depth and off-axis distance. In-house make treatment planning system (TPS) was modified to incorporate the attenuation, scattering and beam hardening effects from the tungsten material. IMRT plans were made for 15 prostate, H&N and breast cancer patients. Intensity map and dose were acquired by the Mapcheck and compared to the TPS predictions. **Results:** The filling of the material is consistent with the maximum discrepancy 2.9% and 1.5%, respectively, for the intraoperator and interoperator filling tests. No compensator quality degeneration was found for two compensators after 30 fractions under normal and strenuous handling. Three dose calculation related parameters were fit using the data acquired on symmetrical and asymmetrical compensators. For 15 patients' plans, the measured intensity maps show that 97%±2% of points in the field have dose difference less than 5% from the TPS calculated. **Conclusion:** The tungsten compensator based IMRT was implemented by our group. The dose distribution discrepancy between the measured data and TPS calculation is small and meets the requirement of clinical needs.

SU-FF-T-104

Rotating Aperture Optimization – Planning and Delivery Characteristics

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Purpose: To describe and evaluate the dosimetric characteristics of a new method for directly optimizing dose distributions with MLC shaped apertures that fully exploit collimator rotation. **Method and Materials:** In direct aperture optimization only the leaf positions and segment weights are used to optimize the three dimensional dose distribution. It has been previously shown that equivalent dose distributions may be generated that have significantly fewer MU and number of segments when compared to fluence based optimization methods. Here we introduce an expansion of direct aperture optimization that includes collimator rotation. Collimator rotation allows for the generation of high spatial resolution dose distributions that are more efficient and have less interleaf errors. IMRT plans for a prostate as well as a nasopharynx target were generated to evaluate the benefits of combining both techniques. **Results:** Dose volume analyses showed that conformal dose distributions may be generated with only 6 segments per beam and with an average 29% reduction in MU when compared to our fluence based leaf sequencing with collimator rotation. Collimator angle was found to be accurate and reproducible to within 0.5 degrees and was independent of gantry angle on our Varian cl21ex linac. The accuracy of the MLC fluence model was also validated using film based verification methods. **Conclusion:** Our results show that rotating aperture optimization is capable of producing high quality dose distributions with a small number of segments and significantly few monitor units than a fluence based IMRT technique. Also, quality assurance tests of collimator rotation IMRT delivery show that current MLC/collimator rotation control systems are capable of delivering the dose distributions accurately and reproducibly. **Conflict of Interest:** This work was supported in part by Varian Medical Systems.

SU-FF-T-105

The Impact of Multileaf Collimator Rotation in IMRT Planning

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Purpose: Collimator angle is a degree of freedom that has seldom been explored in IMRT inverse planning. This work investigates the impact of multi-leaf collimator rotation (IMLCR) on a dosimetric scoring function and lays the groundwork for optimal collimator angle selection in IMRT planning. **Method and Materials:** The scoring function models the maximum deliverable dose at an arbitrary beam orientation and is calculated using a sampling method. To calculate the scoring function, the beam portal is divided into a grid of beamlets based on collimator movement constraints. The intensity of each beamlet is set at the maximum intensity that does not violate the tolerance of any structure intersected by that beamlet. The score is calculated from the fraction of the dose prescription deliverable by each beamlet. The IMLCR is measured as the increase in the scoring function over all collimator angles. **Results:** For large tumors (not fully coverable by the beam portal), the mean IMLCR is 22.2%. Collimator rotation enables more exposure of the tumor to the beam, and thus increases the irradiation of the tumor. For small tumors (fully coverable by the beam portal) with nearby critical structures, the mean IMLCR is 9.3%. Collimator rotation allows critical structures to be better isolated from tumor irradiation. When the tolerance of the nearby structures is high relative to the tumor's prescription, collimator rotation has little impact for small tumors. **Conclusion:** The variation observed in the dosimetric scoring function indicates that collimator rotation can significantly raise the maximum deliverable dose at a given gantry angle. When the tumor is large and/or has nearby critical structures (tolerance <=50% of the tumor's prescription), collimator rotation has the greatest impact and is worth considering. Collimator angle selection could play an important role in improving the quality of IMRT treatment plans.

SU-FF-T-106

A Greedy Segment Generating Algorithm for IMRT

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Purpose: Time is one of the factors that affect IMRT. Decreasing the number of segment is necessary. Knowing the fact that the most optimal number of segments can be reached is a help to estimate the plan's optimization level on time factor. Also an ideal optimal number of segments can help to overcome MLC delivery constraint without increasing the segment number too much. Therefore, greedy algorithm is used to find an optimal number of unconstraint segments. **Method and Materials:** For each IMRT intensity map, an objective function is defined as intensity level multiplied by the area which is the number of grids. Then two- dimension search problem turns into one dimension search problem so that greedy strategy can be used. The search space turns into O(N), which N is the number of intensity level. By sorting the objective function values, the intensity level satisfying that volume with maximum dose is delivered first (MDDF). Iteratively, an optimal segments sequence is generated. Given maximum step size, with the intensity map from IMRT plan being generated by CMS Xio plan system, this number of segments is compared with that generated by slide window algorithm. **Results:** To deliver the same intensity map dose, MDDF algorithm gives the smallest number of segments compared to slide window algorithm from CMS Xio plan system given maximum step size. **Conclusion:** The optimal delivery segments sequence generated by using MDDF algorithm can be an estimate of the IMRT delivery optimization level and the sequence can be a start for embedding MLC hardware constraint by divide-and-conquer strategy.

SU-FF-T-107

Analytical Modeling of Pencil Beams to Include Compensator-Related Beam Perturbations

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Compensators can be utilized as radiation beam intensity modulators. In order to use it effectively, aspects like beam hardening and compensator-induced scatter should be taken into account in dose calculations. The shape of the compensator for IMRT purposes can be realized through inverse planning techniques from a weight matrix. The BEAM MC code was used to generate three phase-space files located above the jaws for generic accelerators based on Philips SL6 and SL25 machines with beam energies of 6, 8 and 15 MV. Each beam energy spectra was extracted with the BEAMDP code and were used in parallel beam source models in the DOSRZnrc MC code. Pencil beam dose distributions were scored in a cylindrical water phantom model. A series of simulations were performed where, each time, the PB was allowed to traverse a different slab thickness (0, 1, 2, 3 and 5 cm) of compensator material located at 33 cm above the water phantom model. The simulations were repeated for different materials that include wax, aluminum, copper, brass and lead. In this study it is shown how the change in the PB dose profiles at each depth can be analytically modeled so that it can be predicted as a function of material thickness. The effect of these corrections are evaluated against full Monte Carlo simulations and were found to replicate CAX depth dose curves within 1.5 percent in most cases. The inclusion of compensator effects in the PB model can then be utilized as a tool to derive the shape of a compensator from a desired dose profile in an efficient way.

SU-FF-T-108

Computing the Regularization Parameter for Inverse Treatment Planning Using the L-Curve Method

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Purpose: Regularization of inverse treatment planning can improve dose uniformity and decrease delivery time of intensity-modulated radiotherapy (IMRT) thus improving the radiobiological effect. We attempt to select an optimal value of the regularization parameter which improves the smoothness of beam intensity functions without deterioration of accuracy of fit in the IMRT optimization problem. **Method and Materials:** We apply to inverse treatment planning the L-curve method which was developed to determine an optimal value of regularization parameter in the discrete ill-posed problems. The method is based on finding the regularization parameter which minimizes the residual norm which is a measure of accuracy of fit and the solution norm which is a measure of smoothness of solution. The main idea of the L-curve method is to plot the smoothing norm as a function of the residual norm for all values of the regularization parameter. Remarkably, this characteristic curve has an L-shaped dependence. The optimal value of regularization parameter can be found at the "corner" of the L-curve. **Results:** We apply the L-curve criterion to the optimization problem of the prostate radiotherapy cancer treatment with intensity-modulated beams. We show the distinctive L-shaped dependence of the smoothing norm as a function of the residual norm. Of great practical importance is the vertical part of the L-curve because the smoothing norm is decreasing and the residual norm remains approximately of the same value. The corner of the L-curve is located using criteria of 1) maximum curvature and 2) minimum total of the residual and smoothing norm. **Conclusion:** The L-curve method can be an important graphical tool for selection of the regularization parameter in inverse treatment planning. The regularization parameter determined using the L-curve provides the optimal trade-off between the smoothness of beam intensity functions and the accuracy of fit.

SU-FF-T-109

Fast Integer-Valued Smoothing of Beam Profiles in Intensity Modulated Radiation Therapy

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Purpose: The delivery time for an intensity-modulated radiation therapy 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 smoothing algorithm which smooths a beam profile to integer-valued intensities. **Method and Materials:** An integer program was formulated that smooths a beam profile to integer-valued intensities. The user specifies the permitted intensity level values, the maximum number of intensity levels, and the percentage of total under-/over-dosage permitted. The IP 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 smoothed plan. The method is tested on two optimal head-and-neck plans, each with seven beams. Both plans were designed so that no pixel is permitted to have an intensity greater than 20. The number

of intensity levels in each beam ranges from 71 to 124. **Results:** For all beams, a feasible integer solution was obtained within 15 seconds. This held true even after the total intensity delivered by the smoothed beam profile was constrained to be either the floor or ceiling of the total intensity of the original beam profile. The smoothed profiles were permitted to use up to ten distinct integer values between 1 and 20. **Conclusion:** This work indicates the potential of a quick heuristic for smoothing complex intensity profiles. The resulting beam complexity reduction improves deliverability of the leaf sequence of each beam. Further research is necessary to determine the effects of local changes in beamlet intensity on the dose received **by the planning target volume and organs-at-risk.**

SU-FF-T-110

Fast Inverse Dose Optimization (FIDO) for IMRT Via Matrix Inversion Without Negative Beamlet Intensities

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Purpose: To optimize an IMRT treatment plan by a matrix inversion method that is very fast, robust and yields a global optimization minimum without negative intensities. Given the availability of online imaging tools, the conformal dose distributions obtained through IMRT and its dynamic delivery features, adaptive radiotherapy becomes an important factor to be considered. A fast and reliable optimization algorithm is crucial not only for designing good radiation treatment plans but also for the successful implementation of future interactive adaptive treatment techniques. **Method and Materials:** The objective function for the optimization of a large number of beamlets is reformulated such that the optimization problem is reduced to a linear set of equations. The optimal set of intensities is found through a matrix inversion, and negative beamlet intensities are avoided without the need for externally imposed ad-hoc constraints. The objective function remains quadratic and the optimal result obtained corresponds to a single global minimum. **Results:** The method has been demonstrated with a test phantom and a few clinical radiotherapy cases using primary photons in the dose calculation only. We have showed that the new method is not only faster but also gives better optimization results. Typical optimization times for a single anatomical slice (2D) (head and neck) using a standard LAPack matrix inversion routine in a single processor desktop computer, are: 0.03 sec. for 500 beamlets; 0.28 sec. for 1,000 beamlets; 3.1 sec. for 2,000 beamlets and 12 sec for 3,000 beamlets. **Conclusion:** We have developed a fast and robust technique to find a global minimum of an objective function that yields excellent results for the inverse optimization problem for the radiation treatment of tumours with IMRT.

SU-FF-T-111

Fast Nonlinear Optimization with Simple Bounds for IMRT Planning

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Purpose: The advent of image-guided adaptive conformal radiotherapy demands the development of very efficient methods of intensity modulated radiation therapy (IMRT) fluence map optimization (FMO). To enable adaptive image guidance with daily IMRT optimization the ability to generate high quality treatment plans "on-the-fly" to correct for changes in patient anatomy during the course of radiotherapy is needed. To this end, we have tested the feasibility of employing analytic convex nonlinear objective functions in a FMO model with simple nonnegative bounds on beamlet fluence. **Method and Materials:** The nonlinear FMO model is based on previously studied voxel-based dose-penalty functions that were approximated in linear and quadratic programming models. Well-known gradient and quasi-Newton algorithms were employed along with an Armijo line search that requires sufficient objective function decrease. A simple projected-direction interior-point method was used to enforce fluence non-negativity. The algorithms were implemented in an in-house treatment-planning system. We tested the following methods: steepest-descent, BFGS, symmetric-rank-1, and combinations thereof. The algorithms were applied to 10 head-and-neck cases. The numbers of beamlets were between 900 and 2,100 with a 3-mm isotropic dose grid. **Results:** The tested methods were all found to be at least as fast as a commercial linear and quadratic programming solver (CPLEX, ILog, Inc.). While no single method was best for all cases, the steepest-descent method typically converged the fastest. **Conclusion:** Nonlinear optimization methods can efficiently solve the IMRT FMO problem in well under a minute with high quality for clinical cases. A simple steepest-descent algorithm was highly successful when combined with methods to enforce simple bounds and to perform a robust line search. Quasi-Newton methods have been successful in solving many large-scale nonlinear programming problems, but provide little advantage for the IMRT FMO problem. In the future, we will test the algorithm's robustness with a larger population of cases.

SU-FF-T-112

First Evaluation of a New Multicriteria Optimization Tool - Investigation of Pareto-Surfaces for IMRT Prostate Plans

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Purpose: The aim of this paper is a first evaluation of the performance of a new multi-criteria optimization (MCO) tool developed for IMRT treatment planning **Method and Materials:** The new MCO-tool computes a set of Pareto-optimal plans by simultaneously minimizing dose indicators for tumor targets and considered organs at risk. For the tumor, the dose homogeneity in the target is maximized for a given, prescribed mean dose while relative deviations to upper equivalent uniform dose (EUD) limits are minimized for organs at risk. The exploration of the solution space is done with a visual navigation tool, which provides control bars for each defined dose indicator. The navigation tool uses real-time interpolation to allow a smooth transition between the pre-computed plans. As a clinical example we consider a simplified prostate case where the only structures to be optimized are the PTV, rectum and bladder. The complete database of plans is visualized using EUD-values of the organs at risk and the standard deviation of the target dose as axes. This approximation of the 3D-Pareto-surface is then examined. The sensitivity of the navigation process on the individual dose indicators is analyzed in terms of the gradients on the Pareto-surface. Moreover, effects of rescaling the target dose homogeneity in terms of TCP-values are analyzed. **Results:** The database provided by the MCO optimization for the simplified prostate case can indeed be presented as a 3D-Pareto-surface.The sensitivity of the navigation process is well reflected by the respective gradient on the Pareto-surface. The rescaling of the target dose homogeneity in terms of TCP values allows studying the sensitivity of the Pareto-surface in terms of the assumed radio-sensitivity of the tumor. **Conclusion:** A first evaluation of a new MCO-tool has been successfully completed for a simplified prostate case with 3 mutually conflicting optimization criteria.

SU-FF-T-113

Incorporating Intra-Fraction Motion Into IMRT Plan Optimization

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Purpose: For treatment planning, clinicians typically compensate for respiratory motion by applying treatment margins that ensure the clinical target volume (CTV) always remains in the treatment field. We have investigated a more sophisticated approach where the pattern of organ motion is directly incorporated into both the dose calculation process and the optimization of IMRT treatment plans, and we have evaluated the degree to which plan quality can be improved by accounting for intra-fraction organ motion during IMRT optimization. **Method and Materials:** In this study, we employed a convolution/superposition based dose calculation that incorporates organ motion. For each photon history, the isocenter is randomly sampled from a probability distribution defined by the respiration-induced anatomical displacement. The resulting blurred pencil beam dose distributions have been incorporated into our IMRT plan optimizations. Comparisons were made between plans optimized using a motion-based dose calculation and those optimized using a static dose calculation. Tests were performed for both a concave target in a phantom and a lung cancer patient. **Results**: For the phantom case, the mean dose to the adjacent organ-at-risk was reduced from 67.3% to 48.4% of the prescribed dose when motion was included in the optimization. For the lung patient, the volume of the right lung receiving greater than 80% of the prescribed dose was reduced from 14.1% to 7.2% when organ motion was included in the optimization. **Conclusion:** The motion-based optimization

accounts for the fact that the CTV will not be at all locations with equal probability and is thus more sophisticated than the application of patient specific margins. Consequently, significant additional sparing of critical structures can be achieved by incorporating intra-fraction organ motion into IMRT optimization. Additionally, the agreement between the predicted and delivered doses is improved because the impact of organ motion has been accounted for in the dose calculation.

SU-FF-T-114

Local Minima in Anatomic Aperture-Based IMRT Optimization

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Purpose: An anatomic aperture-based IMRT optimization program, named Ballista, was recently developed at our institution. Even though studies previously published concluded local minima in full-IMRT optimization were not problematic, early observations with Ballista revealed their nuisance in the case of simplified IMRT. The purpose of this study was to evaluate the extent of local minima and their impact on the optimization process.**Method and Materials**: In Ballista beam weights are optimized by a bound-constrained quasi-Newton algorithm, which cannot escape local minima, even with a quadratic dose-based objective function. Therefore, a high number (20 000) of descents were launched with random initial weights to explore the solution space for a varying number of beams. Actual treatment plan DVHs corresponding to different local minima were analyzed, yielding information on the nature of those minima. **Results**: When only four beam weights were optimized, only a few but very distinctive local minima were found. For a more realistic case of 20 beam weights, the optimization revealed an astonishing number of local minima, almost forming a continuum in the objective function value space. DVH analysis showed local minima generally favor one or more organs-at-risk (OARs) while the other objectives, especially those concerning the target volume, are less than optimal compared with the global minimum. Also, all minima lie on the boundary of the solution space. It was found that limiting the initial beam weights to small values eliminates the vast majority of the solution space containing local minima. **Conclusion:** With Ballista local minima proved to be a major problem. Plans corresponding to different minima differed drastically. In order to give the optimization a "clear shot" at the global minimum, initial beam weights must be limited to small values. This focuses the optimization on improving the target volume objectives since all OARs objectives are initially met.

SU-FF-T-115

Magnitude of Dose Optimization with 2-Field Left Breast IMRT

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Purpose: To quantify the magnitude of dose optimization in 2 opposed tangential-field IMRT for left whole breast irradiation. **Method and Materials:** 6 left breast IMRT cases were randomly selected from our recent IMRT group for analysis. Each had 3 plan trials using 2 opposed tangential fields of 6 MV photons with heterogeneity corrections comprise a wedge paired 3D plan, IMRT plan with lung and heart dose constraints, and IMRT plan without organ avoidance ($IMRT_0$). In all trials the prescribed 50.40 Gy conceals 96% of PTV with clinically acceptable dose homogeneities. PTV was defined as entire involved breast with 5 mm margins from skin surface, lung and heart. A smaller volume was used for IMRT optimization due to electron buildups. The global maximum doses, doses at the cardiac surrogate (1 cm cardiac peripheral ring of in the upper-left quadrant), and volume of the left lung receiving 25.00 Gy dose (V_{25Gy}) were compared. **Results:** Although global maximum doses were improved from 60.99 ±1.62 Gy in 3D plans to 59.96 ±0.97 Gy in $IMRT_0$ plans, no statistical differences ($p \geq 0.10$) were indicated between groups, including IMRT (60.68 ±1.63 Gy) group. Mean doses to cardiac surrogate (12.61 ±6.45 Gy for 3D, 10.77 ±3.68 Gy for IMRT, and 11.83 ±3.08 Gy for $IMRT_0$) were technically undistinguishable. Similar V_{25Gy} for left lung was seen in all 3D, IMRT, and $IMRT_0$ groups (12.8%, 12.5%, and 14.8% respectively). **Conclusion:** Observed 1.02 Gy in prescribed 50.40 Gy or 1.5% reduction in global maximal dose by $IMRT_0$ from 3D plans did not reach statistical significance due to limited sample size. With 96% PTV dose coverage and acceptable dose homogeneities, IMRT or $IMRT_0$ plans did not show meaningful dose sparing for cardiac surrogate or left lung in this investigation.

SU-FF-T-116

Multicriteria IMRT Planning with Equivalent Uniform Dose (EUD) Objectives: Tumor Dose Homogeneity Vs. Critical Structure Sparing

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Purpose: To quantify the tradeoff between target dose homogeneity and critical structure sparing in two typical IMRT situations (prostate, para-spinal). Furthermore, to determine the sensitivity to the response model used for critical structures (maximum vs. mean dose). **Method and Materials:** An EUD-based multicriteria linear programming environment has been developed. In this work, we enforce a tumor minimum dose and compute solutions which efficiently tradeoff the tumor maximum dose and organ-at-risk (OAR) EUD (α·max dose+(1 - α) ·mean dose). Pareto surfaces resulting from different OAR α values are compared. The technique is applied to the RTOG horseshoe target and circular OAR geometry (varying the OAR's size and location), and to two clinical cases. **Results:** Mathematically, if the maximum and mean doses of a structure are correlated then the choice of α does not affect the shape of the Pareto frontier. We demonstrate that this correlation is stronger for smaller OARs (a single voxel has a large impact on the mean), and also for symmetrically located OARs, which have a large set of outer ring voxels near the maximum level, as opposed to asymmetrically located OARs where the maximum dose is more localized. As the dose requirements in the tumor get more strict, we see less variance with α, since the feasible solution space is smaller. We consistently see little to no difference between Pareto surfaces for α from 0.5 to 1. **Conclusion:** By characterizing the conditions under which the Pareto frontier is insensitive to α, we highlight situations where it may not be necessary to know the best value of α, i.e., the exact tissue organization between purely serial and purely parallel. In general we see smooth Pareto surfaces but in some cases there were kinks pointing to outstanding treatment plans.

SU-FF-T-117

On Probabilistic Treatment Planning: A Novel Concept for Including Organ Motion Into IMRT Optimization

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Purpose: We investigate an offline strategy to incorporate interfraction organ motion into IMRT treatment planning. In order to improve the sparing of healthy tissue it was suggested that regions where both, tumor and an organ at risk can be located is irradiated with a lower dose than the dose prescribed to the tumor. This has to be compensated for by irradiating neighboring regions with a higher dose. The approach potentially allows for better sparing of healthy tissue but on the other hand, delivering inhomogeneous dose distributions per fraction is associated with higher risks. In order to make such a treatment planning approach robust and safe, one has to quantify and minimize the associated risks. **Method and Materials:** Practically, such an inverse planning approach can be realized when the optimization of the dose distribution is based on the expectation value of the dose. As a surrogate for the associated risks, we calculate the variance distribution by applying Bayesian inference. The variance term is added to the objective function and is hence minimized in the treatment planning process. Treatment planning is demonstrated for a prostate patient. **Results:** The inverse planning method yields three 3D distributions: a) the expectation value of the dose, b) its standard deviation in each point and c) a dose distribution that maps the dose delivered in a single fraction. The latter shows characteristic dose inhomogeneities within the CTV which are likely to be leveled out when the prostate is in different positions from day to day. However, this may not always be the case. The standard deviation quantifies the average uncertainty of the dose prediction. The dose delivered in a single fraction represents to some extent a worst case szenario. **Conclusion:** Finally, the treatment planner has to find a reasonable tradeoff between potential benefit and risks.

SU-FF-T-118

On the Relationship Between Risk Management and IMRT Treatment Plan Optimization

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Purpose: We assess the suitability of using biological and voxel-based penalty criteria vs. different types of dose-volume histogram (DVH) constraints that have been proposed for fluence map optimization (FMO) in IMRT by developing a rigorous relationship between treatment plan evaluation criteria based on the DVH and voxel-based penalty criteria. **Method and Materials:** Viewing the IMRT FMO problem as the problem of shaping the dose distributions in structures, an analogy was established with risk management problems from the area of financial engineering. **Results:** On the one hand, traditional DVH constraints (bounding the dose received by a pre-specified proportion of a structure) and CVaR constraints (bounding the tail mean dose received by a pre-specified proportion of the structure) can be viewed as dominance constraints of the dose distribution in a structure with respect to some reference dose distribution. On the other hand, most commonly used biological criteria (tumor control probability (TCP), generalized equivalent uniform dose (gEUD), normal tissue complication probability (NTCP)) are equivalent to voxel-based penalty functions, which can be viewed as utility functions that measure the desirability of dose received by voxels. We demonstrated that dominance based on traditional DVH constraints is equivalent to dominance with respect to all non-decreasing voxel-based penalty functions, while dominance based on CVaR constraints is equivalent to dominance with respect to all non-decreasing *convex* voxel-based penalty functions. **Conclusion:** If measures based on and including TCP, NTCP, and gEUD (with $a \notin (0,1)$) are deemed sufficient to describe the effect of a dose distribution on a structure, traditional DVH constraints should *not* be imposed on these dose distributions. However, if traditional DVH constraints are deemed necessary to describe the effect of a dose distribution on a structure, particularly in the case of parallel structures, *e.g.*, the liver, the abovementioned biological criteria cannot be used as alternatives to DVH constraints.

SU-FF-T-119

Optimization of Basis Function Sets to Represent IMRT Intensity Patterns in Inverse Planning

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Purpose: To investigate the use of mathematical basis functions instead of discrete or smoothed beamlets to represent and optimize IMRT beams in inverse planning in order to reduce the degrees of freedom required for producing high quality IMRT plans. **Method and Materials:** Our in-house beamlet-based optimization system was extended to support the optimization of basis function coefficients in order to represent IMRT beams by mathematical surfaces. Comparison studies were performed using a phantom and a prostate case. Four methods were compared; (1) beamlet optimization, (2) beamlet optimization incorporating smoothing in the cost function, (3) Basis function optimization (BFO) using a radial basis function grid (optimization variables are individual function weights), and (4) BFO using polynomials (optimization variables are term coefficients). Results were compared using dose and dose-volume metrics, beam modulation, MU, and robustness to geometric deviations. **Results:** In the phantom, BFO plans were comparable to beamlet plans in terms of dose and dose-volume metrics and superior in terms of using 75-90% fewer optimization variables, requiring 26% fewer MU, containing 38% less plan modulation, and demonstrating improved target coverage when subjected to geometric shifts. Beamlet-based plans that incorporated smoothing met the clinical objectives, with a 16% reduction in MU compared to beamlets. In the prostate, method (3) resulted in a 24% MU reduction compared to method (1) and was less sensitive to geometric changes. Method (2) also produced favorable results in the prostate with a 19% reduction in MU. **Conclusion:** BFO plans were clinically comparable to beamlet plans and superior to beamlet plans with smoothing in terms of MU reduction and lessened geometric sensitivity. The use of basis function sets to represent and optimize IMRT intensity patterns is a promising method to reduce IMRT beam complexity and its implications.

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SU-FF-T-120

Optimization of Energy in Inverse Planning Process

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Purpose: To simultaneously optimize the photon beam energy, orientations (gantry, table), wedge filters and beam weights in aperture-based IMRT, a new inverse planning system has been developed. This system, *Ballista*, uses anatomy-based MLC fields as aperture. It is an alternative for beamlet-based IMRT. The aim of this study is to include the photon energy in the optimization process. **Method and Materials:** *Ballista* uses a fast simulated annealing algorithm to select the optimal configuration of beams with respect to the objectives specified by the planner. To include the energy as a free parameter in the existing overall optimization system, this variable is interpreted by the algorithm as an angle and competes with gantry and table angles. That is, each eligible energy is assigned to a circular section of the space of all possible solutions. In addition to varying the energy of the individual beams, an option was added to the process which allows associating a combination of energies to various segments of a single field. The coverage margin overlap of the fields is naturally adapted as a function of the energy used. **Results:** The effectiveness of energy optimization has been tested on several sites. The lung cancer, which is an interesting example, has provided good results. The value of V_{20} (29,6% vs. 35%) is reduced as well as the mean dose to the heart (14,5% vs. 21,5%). Also, a better tumor coverage (V95% = 97,8% vs. 96,6% and IH = 1,07 vs. 1,10) is obtained in the case of a non-coplanar plan realized with this new approach in comparison with a standard plan (only one energy for the whole plan, 23MV). **Conclusion:** The inclusion of energy gives the optimization process an additional advantage over standard planning, and better close the gap between the optimized approach and the clinical treatment methods.

SU-FF-T-121

Optimizing IMRT Plans with Geometric Uncertainty

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Purpose: To examine the use of robust optimization methods for IMRT planning with geometric uncertainties. **Method and Materials:** A simulation study was performed to compare several approaches of optimizing under uncertainty. We used simple example cases where the optimization produced treatment plans that appear excellent on average, but are clinically unacceptable for some fraction of patients. To remedy this, we first defined an objective function and minimized the objective of the expected dose. Next we generated a sample patient population, computed the objective for each patient individually, and minimized either the average or the maximum of these objectives. **Results:** Cases were identified in which optimizing the expected dose distribution yields unacceptable dose distributions when the dose is delivered. This was particularly evident if a small number of fractions were delivered or if there were systematic errors present. Using robust optimization techniques, we were able to produce acceptable dose distributions for a high percentage of simulated deliveries. For cases with a small number of fractions or large systematic error, the optimal result was similar to a margin approach. Using the same technique with a high number of fractions and small systematic errors yields a better dose distribution than is possible with a margin approach. **Conclusion:** This work indicates that it should be feasible to replace a standard planning treatment volume approach with a robust optimization that automatically takes geometric uncertainty into account. In cases with limited information of systematic errors, such a solution would likely be very similar to the manually designed margins used today. If the uncertainties are random with well known statistics, however, significantly improved tumor coverage and normal tissue sparing can be achieved.

SU-FF-T-122

Progressive Articulation of Radiotherapy Planning Goals Based On Soft-Constraints

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Purpose: Inverse-planning in radiation therapy is involved with multicriteria decision-making problems as it aims to achieve multiple planning goals that are conflicting with each other in target(s) or surrounding healthy tissues. To facilitate an intuitive and explicit way of articulating planning goals, the concept of *soft-constraints* has been implemented into our in-house IMRT planning system using a Goal

Programming (GP) technique. In addition, traditional linear GP has been extended to handle nonlinear goal functions so that the nonlinear metrics highly relevant to clinical protocols (such as DVH, EUD, TCP, and NTCP) can be directly utilized in the planning process. **Method and Materials:** In order to achieve a high convergence speed of the optimization, a gradient-based, nonlinear constraint search algorithm has been used in the implementation of nonlinear GP. The system is designed to handle multiple goals either by a weighted-sum approach (*Archimedean GP*) or lexicographic ordering (*Preemptive GP*). For some planning criteria exhibiting poor numerical performance for gradient searches (e.g., min, max, DVH), surrogate models have been used in such a way that the general idea of soft-constraint is consistently maintained. **Results:** For clinical IMRT cases, the nonlinear GP provides a fast and practical approach to articulate planning goals. Moreover, prioritization of planning goals based on their importance significantly simplifies the RT multicriteria problem representations. The Lagrangian Multiplier values obtained after each level of optimization facilitate informed decisions on goal tradeoffs between different priority levels. **Conclusion:** The soft constraint concept has been implemented for clinically relevant nonlinear criteria in RT inverse planning. Due to the fast search convergence exhibited by the present system, the planning process can be interactive with the decision maker in setting or adjusting appropriate goal levels, leading to progressive tailoring of the individual plan results. Supported in part by NIH grant R01-CA59827

SU-FF-T-123

Robust Optimization Including Effects of Systematic Treatment Errors

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Purpose: Intensity-modulated treatment planning methods have not previously accounted for systematic errors in tumor and tissue locations. We introduce a novel method for including systematic errors during the optimization phase, based on estimated probabilities of systematic geometrical shifts or tissue misidentification(i.e.tumor location). **Method and Materials:** Given a planning geometry, the users supply estimates of the systematic probability that tissues are actually displaced by a given vector("ensemble"). Overall plan quality is based on probability-weighted measures of actual plan realization. Ensembles are estimated here based on dose-convolution with Gaussian probability distributions. Two different objective function metrics based on this paradigm are investigated:the maximum probability of tumor under-dosage is computed using integer variables which divide dose values into under-dose vs. adequate dose. Similarly, the probability that dose to a critical serial normal structure will exceed tolerance is formed into an objective function. A third metric is the uncertainty in the mean dose given to the tumor, averaged over ensembles. Both of these can be mixed with other standard metrics in the IMRT treatment planning optimization process. **Results:** Mathematical formulas for the metrics were derived. We demonstrate the use of ensemble averaging using large-scale mixed integer programming. A systematic setup shift Gaussian probability distribution of 5 mm(half-width) was assumed. A lung treatment plan was tested partly based on minimizing the highest probability of clinical target volume under-dosage. The plan was more robust against systematic errors than the comparable plan without considering the robust metric. **Conclusion:** Systematic uncertainties can be considered directly within the optimization process by averaging over ensembles. The result is increased robustness of the treatment plans. The method of estimating dose to the ensemble treatment plans needs to be studied to potentially improve its accuracy. We have introduced novel metric functions based on explicitly considering the effects of systematic errors, thereby resulting in treatment plans of increased robustness.

SU-FF-T-124

Time-Resolved Aperture Modulated Radiation Therapy

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Purpose: To develop a method to incorporate organ motion into aperture modulated arc therapy treatment plan optimization and evaluate the performance of this method by applying it to prostate cancer cases. **Method and Materials:** A 36 beams treatment plan was prepared using PLUNC treatment planning system to simulate arc therapy. To take into account the effect of organ motion, a 3D distribution function was supposed to describe the displacement resulted from organ motion at different breathing phases. Doses to voxels were calculated using the displacement information at any phase; the deformed doses could be mapped back to the primary breathing phase which is a deformation free phase. Then an optimization objective function about multileaf collimator leaf positions could be defined based on the mapped doses; and adapted simulated annealing (ASA) approach was employed to minimize the objective function subject to clinical prescription requirements. After optimization, an aperture (leaf positions) optimized treatment plan could be gotten. A conventional IMRT treatment plan was also designed for comparison. The aperture optimized treatment plan could be exported to Eclipse treatment planning system and recalculated to observe its performance on Varian accelerators. **Results:** Compared with IMRT treatment plan, aperture optimized treatment plan can produce more conformal dose distribution around the target and critical structures can be spared more effectively, the delivery time and machine MU are also reduced significantly. **Conclusion:** Organ motion can be incorporated into the aperture modulated arc therapy treatment plan optimization with the information of displacement information. A more realistic distribution function can be employed conveniently to produce more significant clinical result.

SU-FF-T-125

Use of Modified Fourier Series for Radiotherapy Optimization

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Purpose: To introduce the use of modified Fourier series as a tool in the optimization of intensity profiles to be used in the calculation of absorbed dose in IMRT and to determine the number of terms in the series necessary to achieve a proper optimization. **Method and Materials:** An analytic kernel is used in conjunction with a modified Fourier series approximation to the unknown intensity profile that optimizes the dose prescribed to a certain region in a mathematical phantom. A computer program was written to perform the optimization process. The advantage of using a Fourier series is that by adjusting a few constants, the exact number depending on the number of terms in the series, the whole intensity profile is modified, instead of having to discretize such a profile and change each of the intensity levels as one searches for the optimum profile. The effect of the number of terms in the Fourier series on the quality of the optimization is also explored. **Results:** For the test case presented, it was determined that the number of terms in the series necessary to achieve a satisfactory solution, determined by a cost function, is 20. One problem, however, is that some of the resultant profiles show steep gradients over short distances, which poses a problem for the delivery process. **Conclusion:** A useful method of calculating intensity profiles for IMRT has been introduced. Further work is needed to compare the quality of the optimization achieved using this technique to that with more established methods. The technique offers a way to introduce changes in the intensity profile that allows for a rapid dose calculation, since the total intensity is a sum of sine and cosine terms for which the dose can be pre-computed prior to the optimization process.

SU-FF-T-126

3D Gel Dosimetry of IMSRT Using Normoxic MAGAT Polymer Gel

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Purpose: To investigate application of 3D gel dosimetry in verification of intensity modulated stereotactic radiotherapy (IMSRT) of intracranial lesions. **Method and Materials:** Radionics treatment planning (XK-RT3) and delivery systems, including a Mini Multileaf Collimator (MMLC) were used in this study. A PVC Head phantom filled with MAGAT polymer gel (Normoxic MAGIC gel with THP as anti oxidant) attached to the GTC frame and stereotactic localizer. The phantom was CT and MR scanned using stereotactic protocols and image fusion was performed for the localization. A four field non-coplanar IMSRT plan was generated using a 6 MV beam with the Radionics planning system and delivered according to our routine stereotactic treatment procedures. For comparison with the planned isodose distribution, the R2 maps were converted to relative dose maps using an R2-dose calibration curve. The polymer dose maps were

then co-registered with the planning dose distributions in an in-house Matlab program which provides reconstructed sagittal and coronal images for 3D evaluation of measured and planned dose. Various isodose levels in the 3D dose map have been compared between the treatment plan calculations and gel measurement. **Results:** Results of this study have shown good agreement between the gel dosimetry and treatment planning calculation. The 2D and 3D agreement was overall better than 5% in dose or to within 3 mm distance for the 80% and 95% isodose levels. The maximum difference for these isodose levels was 10%. **Conclusion:** In this work we have demonstrated that the Polymer gel dosimetry have the ability to accurately localize the high dose regions delivered by intensity modulated stereotactic radiotherapy.

SU-FF-T-127

A Monte Carlo-Based IMRT Plan Re-Calculator

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Purpose: IMRT QA currently is currently a time consuming activity. We hypothesize that IMRT QA labor would significantly decrease if a software tool were available which conveniently re-checked IMRT treatment plans by independently re-computing the expected dose distribution based on the leaf-instructions generated by the treatment planning system. Such a system should have the capability to make detailed comparisons with the original treatment plan. **Method and Materials:** Our research treatment planning system CERR (Computational Environment for Radiotherapy Research) was modified and extended to include the capability of recomputing dose based on leaf-sequences received via DICOM. Three dose computation algorithms have been implemented: (1) a simple pencil beam model which corrects for changes in central axis attenuation, but includes realistic scatter tails, (2) the Monte Carlo code VMC++, and (3) the open source Monte Carlo code DPM (dose planning method). GUI tools were developed to allow for side-by-side dose comparisons and comparative profile dose plots, in addition to DVH comparisons. Initial tests were performed using data generated via the Varian Helios planning system. Comparisons were made beam-by-beam in a simplified QA geometry as well as for total dose. **Results:** Initial results indicate reasonable agreement between the Helios planning system dose distributions and the pencil beam method. Differences with Monte Carlo results were greater, but energy spectral effects have not yet been added to the model. **Conclusion:** CERR provides a powerful and convenient environment to develop an IMRT plan re-calculator. Initial results indicate the basic correctness of data being used for the dose recalculation. We expect to fully develop this system as a helpful tool for IMRT QA. **Conflict of Interest:** This research was supported by a grant from Sun Nuclear, Inc.

SU-FF-T-128

A Practical Method for a Community Radiation Therapy Center to Evaluate the Quality of a Prostate IMRT Program

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Purpose: To present a practical method for a community radiation therapy center to evaluate the quality of a prostate IMRT program. **Method and Materials:** The center transitioned from treating prostate cancer with 3DCRT to IMRT in January of 2004. Our quality assurance program included point dose verification via an ionization chamber measurement, planar dose distribution check with Kodak EDR2 film, and a dose calculation check with an independent monitor unit calculation program. RPC phantom measurements found agreement between planned and delivered doses of 1% and 2 mm. After treating approximately 100 patients with IMRT, we reviewed a sample of patient records that received the intermediate to high-risk dose from each technique (73.8 Gy 3DCRT, 76 Gy IMRT**). Results**: Ionization chamber measurements were within 1.1 +/-0.7% of the plans' predictions, point dose calculated by the independent MU check software agreed with the treatment plans to within 0.8 +/-0.7%, and the film measurements demonstrate a dose distribution agreement within 2.3 +/-0.8 mm for the 85% isodose line and 2.0 +/-1.3% for the 50 % line. The mean dose to the prostate increased from 75.87 Gy for 3DCRT to 80.04 Gy with IMRT ($p<0.0005$). The percent of the rectum receiving more than 65 Gy decreased from 21% to 12% with IMRT ($p<0.0005$). The percent of the bladder receiving more than 65 Gy was unchanged (16% for IMRT and 15% for 3DCRT, $p=0.2651$). The records indicate that the frequency of GI Grade II toxicity decreased from 22% for 3DCRT to 9% for IMRT. Grade II GU toxicity increased from 30% with 3DCRT to 56% with IMRT, perhaps because of the higher dose to the urethra within the prostate volume. **Conclusion**: This efficient study of patient records can provide a community center with an objective evaluation of the quality of a prostate IMRT program.

SU-FF-T-129

A Practical Monte Carlo MU Verification Tool for IMRT Quality Assurance

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Purpose: Quality assurance (QA) for intensity-modulated radiation therapy (IMRT) treatment planning and beam delivery, using ionization chamber measurements and film dosimetry in phantom, is time consuming. The Monte Carlo method is the most accurate method for radiotherapy dose calculation. However, a major drawback of Monte Carlo dose calculation as it is currently implemented, is its slow speed. The goal of this work is to bring the efficiency of Monte Carlo into a practical range by developing a fast Monte Carlo monitor unit (MU) verification tool for IMRT. **Method and Materials:** A special estimator for dose at a point called the point detector has been used in this research. The point detector uses the next event estimation (NEE) method to calculate the photon energy fluence at a point of interest and then convert it into dose by mass energy absorption coefficient assuming the presence of quasi charged particle equilibrium. An improvement to this method is to initiate the electron transport at the surface of a sphere centered at the point of interest to account for the effect of electron disequilibrium and patient heterogeneous anatomy. The point detector method is implemented with the MCNP Monte Carlo code system. **Results:** The MU verification tool can be used for both patient dose verification and phantom QA calculation. Dose calculations in a water phantom have been performed using the point detector method. Results were compared with direct Monte Carlo simulations using EGS4/MCSIM, which is a well- benchmarked Monte Carlo code. The results between the point detector and MCSIM agreed within 1%. A factor of 10 speedup can be achieved with the point detector method compared with direct Monte Carlo simulations. **Conclusion:** An effective and efficient Monte Carlo MU verification method has been developed as a practical routine procedure for IMRT QA.

SU-FF-T-130

A Routine QA Procedure for the Varian Millennium MLC Used for Step and Shoot IMRT

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Purpose: To create a routine QA procedure that would effectively test the accuracy of a Varian Millenium MLC System that was used heavily for step and shoot IMRT. **Method and Materials:** We researched the literature to compare published QA procedures and extracted various tests to use at our centers. The procedure that we created consisted of 4 simple monthly tests, 5 additional quarterly tests, and 8 additional annual tests. The monthly tests were evaluated visually and took a minimal amount of time to perform. The quarterly and annual tests involved irradiating more films and analyzing most of them with the RIT113 version 4.1software. The annual tests were those provided by Varian in the "QA Tests Patterns and Procedures" manual and the RIT113 software included specific options for evaluation. **Results:** The machine parameters and MLC shapes were input to the Impac R&V System. Therefore the tests were simple and fairly quick to run. The analysis however was time consuming because all films must be scanned with a Vidar scanner and evaluated with the RIT113 software. The advantage of using RIT113 was that the QA documentation became organized and efficient. **Conclusion:** The literature contains many different MLC QA tests for a variety of equipment configurations. Furthermore we found that the AAPM Task Group #50 Report gives guidelines for MLC testing but does not list detailed tests. By combining several references and importing the tests in Impac, our MLC QA procedure has proven to be successful with minimal time expense. Within a very busy center performing IMRT treatments, the physicist is usually consumed with patient specific QA. This type of QA isn't usually precise

enough to pick up small MLC inaccuracies and additional QA tests are necessary.

SU-FF-T-131

An Analytic Approach to Film Based Absolute Dosimetry for IMRT

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Purpose: To analyze the uncertainties in film based absolute dosimetry for patient specific quality assurance in IMRT. **Method and Materials:** In our institution, we use EDR2 film for the planar dose quality assurance measurements in patient specific IMRT. Our film dosimetry system was calibrated using a step wedge pattern for the linac and a step valley pattern for HiArt Tomotherapy machine. The dose to each step was measured using a calibrated ion chamber. All films were processed using a Kodak processor and subsequently scanned using the VXR-16 Vidar scanner driven by the RIT software. The film optical density to dose response curves for six months were collected and analyzed. A fitting equation was derived and a systematic analysis was performed to evaluate whether a film calibration needs to be performed daily for the film dosimetry system. **Results:** Absolute dosimetry with film is subject to machine output fluctuations, film processing, film scanning and other sources of uncertainty. Based on our analysis, we found that the film processing error can be up to 7% (1SD), which corresponds to 1% (1SD) error in absolute dose (as determined from film dosimetry). The film scanner number can be correlated to absolute dose using a logarithmic fit to our measured data. Several step-and-shoot and TomoTherapy IMRT QA plans were evaluated using this method. The QA compares very well against the daily film calibration technique. **Conclusion:** Absolute film dosimetry for IMRT is feasible, and when the processor is properly maintained, a less than 3% error can be achieved in the calculation of dose. Once several dose response curves for the film are collected, an analytical fitting curve can be used in lieu of daily film calibration.

SU-FF-T-132

An Investigation of the Accuracy of Film Dosimetry Using EDR2 Film for the Point Dose Determination for IMRT-QA

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Purpose: To investigate the accuracy of film dosimetry using EDR2 film for point dose determination for IMRT-QA. **Method and Materials:** This work compared point doses measured by EDR2 film with those by chamber for 135 IMRT cases. The dose to the measurement point was about 200 cGy.

EDR2 films were read and analyzed using a Vadar Scanner and the RIT Film Dosimetry System. In order to reduce the uncertainty of film dosimetry, the following measures were taken: (1) the H&D curve was obtained by placing the calibration films at 4 cm in solid water, and at the same depth of solid water EDR2 films were irradiated with planned IMRT fields for QA purpose; (2) each photon beam energy has its own H&D curve; (3) the length of time between film exposure and processing was always kept within 10 minutes since processing time delay affects the dose response of the film; and (4) the measurement point was chosen to be at low dose gradient region.

For chamber dosimetry, a 0.3cc PTW ion chamber (type 31003) was used in solid water. **Results:** Comparisons of point doses measured by chamber and those by film show that, for 135 IMRT-QA measurements, 51% of point dose values from EDR2 films match corresponding dose values from chamber to within ±3%, 72% of dose values to within ±5%. However, for 28% of measurements, the deviation between dose values from EDR2 film and those from chamber is larger than ±5%, the maximum deviation being 9.3%. **Conclusion:** If the dose value determined by chamber can be considered as the "true value", then we believe that the accuracy of EDR2 film still needs to be improved for point dose determination although the film is good for verification of relative dose distribution in our experience.

SU-FF-T-133

Analysis of the Correlation Between MLC File Parameters and IMRT QA

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Purpose: We examined IMRT beams for potential correlations between properties of the MLC files and the agreement between the expected and measured dose distributions for patient specific QA. **Method and Materials:** We studied the significance of the incomplete modeling of the MLC rounded leaf edge in the Pinnacle-v6.2b TPS. Test beams were generated with opposed leaf separation widths of 0.5, 0.7 and 1.0 cm. Different percentages of the total MU were delivered with these small separation segments with the remaining MUs delivered via an open field. A diode array was used to measure the delivered dose. The agreement between the planned and delivered beams (pass-rate) was based on a 3%-3mm dose-difference and distance-to-agreement criteria. A software program examined the MLC files and identified opposed leaves separations less than 0.5, 0.7 and 1.0cm and calculated the fractional area (Area) exposed by the separated leaves as well as the percentage of MUs (%MU) delivered via that segment. Correlations between the product of the %MU and Area and the pass rate were examined. **Results:** For the test beams, strongly statistically significant Spearman correlations were found for %MU*Area and pass rate for leaf separations of 0.5 and 0.7cm (ρ=0.9 and ρ=0.8). An analysis of the 350 step-and-shoot beams indicates a possible correlation between the pass rate and the %MU*Area value for separation thresholds of 0.5 and 0.7cm (ρ=0.5 and ρ=0.51). **Conclusion:** The pass rates and leaf separation were correlated in the test beams, however the ability of the small separations to predict pass rates in real beams was not significant. For real beams, there are contributing factors such as interleaf leakage and leaf position errors which can cause the low pass rates. For 1.0cm separations, the pass rate was 100% indicating that the systematic errors for leaf separation greater than 1cm were not significant.

SU-FF-T-134

Automated Quality Assurance Using Treatment Delivery Sinograms

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Purpose: Adaptive image-guided radiation therapy (IGRT) is a new treatment paradigm where 1.) Patients are positioned daily using CT-guidance and 2.) The delivery is adjusted daily to compensate for changes in the volume, position, and deformation of anatomy. Because the adaptation is performed while the patient is on the treatment table, it is impossible to perform quality assurance (QA) testing. This goal of this study was to develop new image analysis tools for the purpose of automating patient specific QA for adaptive IGRT. **Method and Materials:** Detector data in the form of sinograms were acquired during helical tomotherapy delivery using an arc-shaped detector array that consists of 738 xenon-gas filled detector cells. A software program was developed that analyzes tomotherapy sinograms by comparing one treatment delivery sinogram with a reference treatment delivery sinogram. At present, the software offers the following options: 1.) Analysis of ionization chamber entrance doses, 2.) Sinogram exit dose error detection, and 3.) Sinogram leaf error detection. **Results:** The first step in validating the QA system was to determine the threshold for error detection. Delivery sequences were modified by inserting MLC errors of known magnitudes. MLC errors that corresponded to 20, 10, 1, 0.1, and 0.01 percent errors in dose for 1 projection (i.e. segment) were purposely inserted into QA delivery sequences. The Automated QA tool was consistently able to detected errors of 0.01 percent or greater from the detector data at all tested data compression ratios. However, automated MLC leaf error detection would only function using uncompressed data. **Conclusion:** Multiple techniques have been developed for analyzing sinogram detector data during, and after tomotherapy treatment delivery. A combination of these error detection methods will be used to perform automated quality assurance for conventional and adaptive radiation therapy. **Conflict of Interest:** Research supported by TomoTherapy, Inc.

SU-FF-T-135

Complex IMRT Plan Verification Using a Commercial MU Calculation Package

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Purpose: The general availability of IMRT treatments is constrained by the need to perform dosimetry measurements as part of the patient plan verification. While secondary IMRT MU calculators have been

successfully used to validate some plans for a restricted number of sites, these calculators have suffered from unacceptably large uncertainties when applied to sites confined to the head and neck region. A strategy to reduce these calculational uncertainties has been developed which permits a greater use of IMRT MU calculators and reduces the need for dosimetric measurements, enabling a larger patient population to receive the benefits offered by IMRT treatments. **Method and Materials:** Segmental IMRT head and neck treatments were developed using the Pinnacle 6.2b inverse planning module. The IMRT treatment plans where then calculated on a CT image set of PMH IMRT phantom, and validation points corresponding to key target and avoidance regions where identified. The dosimetric data corresponding to these points was exported to RadCalc, a commercial IMRT MU calculator, and the calculations were compared to Pinnacle calculations and in-phantom measurements. **Results:** A total of 10 clinical patient cases, each containing 7 to 9 gantry angles, were assessed. Agreement was assessed on basis of total dose delivered to the point of calculation. The measured and RadCalc calculated doses were found to agree within 3% at the high dose point and 5% at the low dose point in all cases, while the Pinnacle calculated dose was found to agree with the measured dose within 2.5% at the high dose point, with deviations as large as 13.5% observed at the low dose point. **Conclusion:** In-phantom IMRT verification calculations of the total dose yields similar results as in-phantom measurements. Consequently, a secondary MU calculator can be used to verify IMRT treatment plans and reduce the frequency of validation measurements.

SU-FF-T-136

Correlation Between IMRT Plan and Delivery Quality for 9 Treatment Planning Systems

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Purpose: This paper inter-compares measured vs. calculated IMRT verification data with the planning quality data from 9 treatment planning systems (TPS) to determine if the benefit of the TPS that generates the best plans on paper is realized when the dose is actually delivered. **Method and Materials:** A collaboration of 8 centers with 9 TPS has previously presented results of a dosimetric comparison of IMRT plans using a consistent CT dataset for prostate, head and neck, and lung cases. Now these plans have been exported to phantoms and irradiated with the planned beams by each participating institution. Measurements have been made with an ion chamber at isocenter and film in a coronal plane 1 cm anterior to isocenter to determine the degree of agreement between the TPS dose and the measured dose. Also, the percentage of pixels exceeding a Gamma of 1.0 were tabulated for each system and site. A point system based on rank was applied to both Gamma values and absolute dose agreement for each system and site. The quality of the patient-based treatment plans was also quantified by a point system based on the ability to meet the stated dose-volume goals. The total points earned by the plans were correlated to the points earned by the QA results. **Results:**. Both the mean and standard deviation of the differences between measured and calculated absolute dose were within 3%. There was no trend for the Gamma values by site and TPS. The correlation of plan quality and dose calculation accuracy was weak. **Conclusion:** Although there were differences found in dose calculation accuracy between 9 TPS in both absolute dose and isodoses, there does not appear to be a correlation between plan quality and ability to deliver the planned doses.

SU-FF-T-137

Development of a Software Tool for Generating Predicted Dose Images From Pinnacle Dose Maps for the Purpose of IMRT Quality Assurance Using PortalVision

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Purpose: To develop and evaluate a method of importing the predicted dose maps of patient treatment fields generated by the Pinnacle treatment planning system (TPS) into the dosimetry module of Varian's PortalVision electronic portal imaging system (EPID), for the purpose of verifying planned IMRT fields. **Method and Materials:** PortalVision, when equipped with the dosimetry module, is equipped with tools to perform relative dose comparisons of dose images acquired by the EPID vs. predicted dose images generated by a TPS.

Treatment plans were created using the Pinnacle TPS. Dose maps of individual fields were saved as files using Pinnacle's Planar Dose Map function. The dose maps were calculated in a geometry equivalent to that of the detector panel. Using in-house developed software, the dose map files were converted to the correct predicted dose format and imported into the PortalVision software.

Predicted dose maps were generated for open square fields of several standard sizes, wedged fields, and IMRT fields. The IMRT fields were taken from typical prostate, and head and neck patients. Fields from ten IMRT patients were evaluated.

The treatment fields were delivered using a Cl2100EX accelerator. Point dose measurements were obtained from the acquired dose image and compared with film measurements. The predicted vs. delivered dose distributions were evaluated using the available PortalVision tools. The results were compared against those of films analyzed using RIT. **Results:** Point dose measurements made with PortalVision in areas of high dose, low dose gradient agreed with film to an average of +/- 3%. Dose Difference and Gamma results agreed with film results to within +/- 3%. **Conclusion:** This work shows that a predicted dose map from a TPS can be modified and imported into Varian's PortalVision software in order to perform IMRT patient QA with accuracy comparable to traditional film methods.

SU-FF-T-138

Dose Variation On the Simultaneous Irradiation of Head and Neck (H&N) Cancer and Supraclavicular Nodal Fields with Step-And-Shoot IMRT

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Purpose: IMRT QA is just a single event in the entire treatment. The objective of an IMRT QA may be expanded to include temporal variations such as dose linearity, MLC leaf positioning, etc.. **Method and Materials:** IMRT QA is carried out for an H&N case covering simultaneously the nodal regions in the supraclavicle. In addition, dose linearity is studied with ion chamber measurements in the MU range 1-100, and field size range from 1x1-5x5 cm^2, including elongated fields. A 2D diode array device is used to study the consistency of dose delivery by repeating the irradiation of selected fields ten times. The dose delivered and the distributions in all repeated irradiations are compared. The dynamic positioning of leaves during dose delivery is recorded. **Results:** The routine IMRT QA yielded acceptable agreement (4% in dose and over 2%, 3mm distance-to-agreement is >90%) between calculation and measurement. Dose linearity is within 2% for all fields except 5% for 1 MU. The linearity holds even for small MU segments, down to 1x1 cm^2. The maximum shift in the 90% isodose line in 10 irradations > 5mm, and up to 1 cm for the 50% line. For fields with average MU/segment in the range 0.9-2, the dose variation is <1.5% in 10 repeated irradiations. While 90-95% of the dynamic leaf positioning are within 0.5 mm, about 3-6% are >10 mm. **Conclusion:** The standard QA acceptance criteria may not be adequate to gauge the accuracy of dose delivery, especially for sliding window techniques. The effect of the isodose shift may compromise the dose constraint to adjacent critical structures. A composite QA process incorporating leaf positioning may be warranted for comprehensive QA. Any deviations from calculation should be evaluated in the context of composite TCP and NTCP.

SU-FF-T-139

Dosimetric Effect of Jaws for Small MLC Fields in 6 and 15 MV Photon Beam

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Purpose: This study measures how the relative position of the jaws above the MLC could affect the dose characteristics of a small field. The study

focused on the variations in the percentage depth dose (PDD), beam profile and output of the small field when the jaw-ends were moved away from the leaf-ends, that is, when the leaf leakage/transmission and jaw scattering were changed. **Method and Materials:** A big scanning water tank system (RFA 300, Scanditronix Medical AB) generally used in the commissioning was used to measure the beam characteristics. A photon diode (Scanditronix Medical AB, PDF-3G) was used to measure both the PDD and beam profile for both 6 and 15 MV photon beam. To measure the output, a micro-ionization chamber (Scanditronix Medical AB, RK8304) was used. **Results:** It is found that moving the jaw to different positions away from the leaf-ends will increase the output and penumbra width for the small fields. Such increase is particularly more significant when the field size is small (0.5 x 0.5 cm^2), and when the jaw-end is at about 1 to 2 cm from the leaf-end, when the degree of increase changes quickly. **Conclusion:** Measurement is important in Intensity Modulated Radiotherapy because the jaw cannot cover all the leaf-ends in a segment of irregular field completely. This results in additional dose contributed by (1) the end surface of the jaw, (2) the leaf-end and (3) the inter- and intra-leaf leakage/transmissions during the dosimetric measurement. In addition, most of the conventional treatment planning systems ignore these effects in the dose calculation. It is suggested that similar measurements will be carried out in the IMRT commissioning to provide information to physicists in reviewing the treatment planning system's accuracy with regard to the leaf leakage/transmission and the jaw effects.

SU-FF-T-140

Dosimetric IMRT Plan Verification and Daily Quality Assurance with a Two-Dimensional Ionization Chamber Array

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Purpose: IMRT requires a more specified quality assurance program than the conventional techniques. In this work we present our solution for a full IMRT quality assurance program with two-dimensional ionization chamber arrays (2D-ARRAY, PTW-Freiburg) containing daily checks and individual dosimetric plan verifications. **Method and Materials:** The used array (type 10024) has 27 x 27 ionization chambers arranged in a plane, with an entrance window of 5 mm x 5 mm each. The centers of the 729 single chambers are positioned at 10 mm distance from each other. **Results:** Our quality assurance program is divided into two parts: On a daily basis, as a morning check, the dose at the central axis, the flatness and symmetry as well as the MLC calibration and light/radiation field congruence are evaluated by a single measurement. For a patient specific IMRT plan verification, the calculated dose distribution of the patient is exported to a CT containing the phantom set-up with the 2D-ARRAY. The corresponding IMRT sequence is exported to the linear accelerator. The values calculated for the plane of the 2D-ARRAY and the values measured with it are then compared. **Conclusion:** The daily QA program has been extensively tested. All important field parameters can be obtained in a single measurement per energy. Furthermore MLC misalignments can be detected with an accuracy of less then 1.0 mm, allowing an early warning for a necessary MLC recalibration.
The described program for IMRT plan verification has been proved to be very useful for an easy and fast pre-treatment quality assurance. The error detection capabilities will be discussed in detail and shown to be sufficient for standard IMRT plans. **Conflict of Interest:** This work was performed in collaboration with PTW-Freiburg Dr. Pychlau GmbH, Freiburg, Germany.

SU-FF-T-141

Effects of Lung Inhomogeneity for An Intensity Modulated Field

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Purpose: To study the effects of inhomogeneity for intensity modulated fields using slab phantoms. **Method and Materials:** Tissue equivalent solid slab phantoms (20x20 cm^2 and varying thickness) were used to create inhomogeneous medium. A 4-cm thick lung equivalent material was used to simulate lung inhomogeneity. Radiographic films were placed at 1-cm upstream and at 2-cm downstream positions relative to the lung material along the beam axis. Note that the electronic equilibrium in the beam direction was achieved at these locations. Ten 5-mm wide bar patterns placed at every 1-cm were generated using the sliding window technique for intensity modulated fields. We used a 6MV photon beam of a Varian 2100CD with 52-leaf MLC. A concept of modulation transfer function (MTF) was applied for the analyses. **Results:** The bar pattern of the beam intensity was smoothed at the depth of 5-cm in the phantom, becoming a dose profile similar to sine waves on the plane transverse to the beam axis. There was a clear difference of dose profiles between the homogeneous case and the 4-cm lung case. The latter exhibits a smaller attenuation of the amplitude of the sinusoidal waves. MTF measurements showed that there were five peaks between 0 and 0.2 mm^{-1} for the homogeneous case; but, there were only three for the lung case. The MTF values of the sine waves were 0.783 and 0.914 for the homogeneous and the lung cases, respectively. **Conclusion:** Using a sinusoidally modulated field, we have found that the effects of 4-cm thick lung are to increase the amplitude of the sine waves and to smooth the narrow fields. The application of MTF concept helps us with deeper understanding of the heterogeneity effects for intensity modulated fields

SU-FF-T-142

Error Analysis of An Independent MU Calculation Program for IMRT Fields

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Purpose: To evaluate the accuracy of an independent monitor unit calculation program for dose-per-MU verification of IMRT fields. The MU calculation program runs on a PC and is based on a scatter-factor-based empirical model to determine D/MU. This algorithm provides a head-scatter model for IMRT fields. **Method and Materials:** The D/MU of IMRT fields at the same point (mostly the isocenter) was compared between treatment planning system and the independent MU calculation program. Here MU for an IMRT field refers to the total MU. The fractional MU of each segment of an IMRT field, defined as the MU for the segment per total MU, was assumed to be the same. The commercial treatment planning system is based on a pencil-beam convolution algorithm with headscatter modeling. D/MU of a subset of IMRT fields, which is delivered to an IMRT phantom, was compared among the treatment planning system calculations, the independent MU calculations, and measurements. **Results:** Among 24 patients examined, the difference of D/MU for all IMRT fields delivered to a point agreed to within 7% for 91% (22/24) of patients, the same acceptance criteria using measurement, with the maximum error of 8.4%. This error is slightly worse then the measurement, where 100% of patients are within 7% limit. When each individual IMRT field is examined, 21% (33/160) of the fields have a discrepancy larger than 7%. Most of those fields (78.8%) lie in the valley region of an IMRT field. **Conclusion:** The independent MU calculation program can effectively verify the dose calculation accuracy for most IMRT fields. Only in few instances (9%), which invariably involves the calculation point to be in very low dose region, actual measurements are needed to further verify the accuracy of dose calculation for IMRT field.

SU-FF-T-143

Evaluation of the Lung Dose Calculation Accuracy for An IMRT Planning System

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Purpose: Image guided treatment of lung provides the ability to deliver dose precisely to the target, however, lung dose calculation is often difficult and might be the weakest link now in the chain of lung IGRT. The purpose in this work is to find out the accuracy of a common TPS system in lung dose calculation. **Method and Materials:** So far lung dose measurements have been done only in slab geometry and for a single beam. In this work, we used a realistic lung phantom and delivered all fields of realistic IMRT plans. The phantom is supplied with cylindrical inserts, made of lung, bone, and tissue, which were used to load the dosimetry equipments. The dose to the phantom was calculated, for 10 IMRT treatment plans, with the Corvus system. Validation of the calculated dose was performed with LiF thermoluminescent dosimeters (TLDs) measurement, Ionization chamber measurement, and 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 10% relative to the Monte Carlo results, and by 7% relative to the chamber measurements. The TLDs dose results show better agreement to the Monte Carlo results than to the Corvus results. In bone the Monte Carlo agreed well with both TLDs and chamber measurements (within 3.5%) while Corvus dose was 6.5% different. The dose to the tissue shows good agreement (within 2%) between all the dosimetry tools. **Conclusion:** The dose calculation accuracy in lung has been estimated for IMRT planning system. It indicates some better dose algorithms might be needed in order to have an accuracy of a few percent.

SU-FF-T-144

Feasibility of a Novel Gafchromic Film for Routine IMRT QA

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Purpose: To assess the feasibility of using an improved Gafchromic film, EBT (International Specialty Products), for routine IMRT QA. **Method and Materials:** EBT films were evaluated for clinical use in IMRT QA by comparing their performance to the widely used Kodak EDR2 film. As a clinical test, one hybrid phantom plan, consisting of seven IMRT fields, was calculated on a commercial treatment planning system with prescription levels of one to five Gray. The plans were delivered to EBT and EDR2 films loaded in a Bluebox film phantom. The films were digitized on Vidar VXR-12 film scanner and analyzed using the RIT film dosimetry system. The percentage of pixels (exceedence) with plan/film dose difference above 5% tolerance level was used as a metric for film comparison. The symmetry and flatness for the same dose range were also determined for both types of films. **Results:** For EBT films, flatness and symmetry in two orthogonal directions improved as dose increased. Correlation between the plan and EBT film improved with increased dose, as indicated by a decrease in the exceedence (%): 22.9(1Gy), 11.9(2Gy), 11.2(3Gy), 6.6(4Gy), 4.1(5Gy). EDR2 films exhibited a different trend: 12.7(1Gy), 7.7(2Gy), 12.6(3Gy), 13.4(4Gy), 26(5Gy). Delivery time increased from 6 minutes for 1Gy plan to 9.5 minutes for 4Gy plan using dose rate of 600MU/min. **Conclusion:** At higher doses, EBT films show results comparable to, or improved over, EDR2 films. They demonstrate improved flatness and symmetry and IMRT QA results with increased dose. The additional 3.5 minutes necessary to deliver 4Gy to EBT film in order to achieve better results than with the EDR2 film is more than compensated by the convenience of using Gafchromic film. Further improvement of the digitization procedure and increase of the signal-to-noise ratio of EBT film should allow even lower dose for routine IMRT QA.

SU-FF-T-145

Finding the Optimal Digitizer for Use with Gafchromic EBT Film

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Purpose: When performing a QA procedure using film the accuracy of the calculated dose is dependant on the digitizer. The ideal digitizer would have high sensitivity, density stability and uniformity. Our goal is to find the best scanner for use with the newly introduced Gafchromic EBT film. **Method and Materials:** We first exposed the EBT and EDR2 films to IMRT patterns with a maximum dose of 200cGy and generated a calibration film, which consists of 26 dose steps from near zero to 250cGy. The films were scanned on our Vidar Dosimetry Pro, as well as two Epson and two Microtek flatbed scanners. Film dosimetry software was used to analyze the films, by comparing the generated dose maps from EBT films to EDR2 films. **Results:** In comparison we found that the EBT film performed best on the Epson scanners and yielded a sensitivity 1.5 times greater than the Vidar, due to the film's absorption peak matching the red color channel of the Epson. Microtek's sensitivity equals the Epson, but noise levels are up to 5% compared to 1% on the Epson and Vidar. In comparing EBT to EDR2 we found there is no difference when scanned on the Epson or Microtek, but the Vidar showed high dose levels to be 8% lower with EBT due to a large point spread function altering the calibration curve. Comparing scanners shows that the noise level in dose is reduced on the Epson by 1.5 with EBT over the Vidar, while EDR2 remains the same and equal to the EBT on Epson. Microtek yields noise up to five times greater than the Epson. **Conclusion:** Digitizing on the Epson scanners utilizing the red color channel yields the best results. Similar results are attainable if an average scanning technique is utilized with Microtek scanners.

SU-FF-T-146

How Monthly QA Affect the IMRT QA Result

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Purpose: According to TG 40, film demonstrates the width and length of field between 9.8cm to 10.2 cm are considered acceptable for a 10x10 cm field size. This work is to demonstrate under these two accepted scenarios, how IMRT QA results are affected. **Method and Materials**: Five IMRT QA plans are generated with each gantry angle set to the nominal angle (down onto phantom surface) and isocenter located at 100cm SAD, depth 10 cm. A 2D diode array MAPCHECK was set up and radiated according to the QA plan. These five QA plans were repeatedly radiated on four different days. The first exposure was done prior to the field adjustment with field size 9.8x9.9 cm for a 10x10 cm field size; the subsequent three measurements were done in three different days after the field adjustment to 10.12x9.9cm. Absolute Measured dose is compared to planned absolute dose for each detector. We also compared the measurement data with the different beam modeling sigma parameter. **Results:** Prior to the field adjustment, the passing rate for these five QA plans ranged from 42.1% to 78.3 % with 3% Dose difference and 2mm of DTA. The passing rate increased from 64.5% to 91.8% with 3% Dose difference and 3 mm of DTA. Table I present these comparisons. After the field adjustment, the passing rate range from 91.5% to 98.3 % with 3% Dose difference and 2mm of DTA. Table II, III and IV present the comparisons. **Conclusion:** Even though the field size for 9.8x9.9 cm is acceptable for a 10x10 field size for monthly QA, the consistent reduction of the field size (2mm) all the way to 1x1 dramatically impacts IMRT QA results much more so than the adjusting the sigma parameter on the beam modeling data.

SU-FF-T-147

Improved Calibration Method of EDR Films for IMRT-QA

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Purpose: Due to film processing variation and the optical density not being linear with the dose, a full calibration has to be obtained for every IMRT-QA with film. We are proposing the application of a linearization method and the use of a single dose calibration EDR film for relative and absolute dose measurement in IMRT-QA. **Method and Materials:** The linearization method was studied for the EDR films using 6, 10 and 15 MV photon beams. The films were developed in a Konica film processor, then scanned with a Vidar VXR-16 scanner and analyzed using RIT-114 version 4.1. A standard 30-point calibration curve was obtained with the 6 MV beam. Using the method developed in a previous paper, a curve fitting was obtained for a sigmoid expression modulated by a 3rd degree polynomial: $\text{ApparentDose} = b(1+a_1x+a_2x^2+a_3x^3)\,[\log(m)-\log(m-x)]$; where x is the net optical density, m is the net saturation density, b, a_1, a_2 and a_3 are parameters of the model. **Results:** A value of 1870.1945 was obtained for b that is a parameter related to the dose unit. The net saturation density was 3.5587 for our system. The parameters a_1, a_2 and a_3 are, respectively, -0.4551, 0.1167, -0.0134. For every IMRT-QA a spreadsheet is used to obtain a 70 point calibration curve for RIT, using only one exposed film developed together with the composed and enface films, obtaining <5% uncertainty. **Conclusion:** Some softwares are available to make film dosimetry in IMRT QA less cumbersome, however daily calibration still remains a time consuming procedure. Absolute dosimetry requires a full calibration every time film is used. The linearization method presented here is being used in our department for isodose comparison and for absolute measurement at calculation point. The overall time is reduced while obtaining uncertainty comparable to the existing methods.

SU-FF-T-148

IMRT Head and Neck Phantom Irradiations: Correlation of Results with Institution Size

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Purpose: To analyze the results from 136 IMRT H&N phantom irradiations. **Method and Materials:** A mailable anthropomorphic IMRT head and neck phantom was irradiated 136 times by 104 institutions. Some

institutions irradiated multiple times. Institutions imaged the phantom, planned an IMRT treatment, performed their routine IMRT QA checks, and irradiated the phantom according to their plan. The phantom contained imageable structures representing a planning target volume (PTV) close to an organ at risk (OAR), simulating an oropharyngeal tumor and the spinal cord. The phantom also contained a secondary PTV that simulated peripheral nodes. TLDs were placed in each structure and a set of orthogonal radiochromic films intersected in the primary PTV. The following criteria were used to evaluate the measurements: TLD/institution dose – ± 7%; distance-to-agreement in the high dose gradient region near the OAR – ≤ 4 mm. The failure rate of institutions that housed 3 or fewer megavoltage therapy machines was compared to that of larger institutions. **Results:** 41 irradiations failed to meet one or more of the criteria. 24 of the failures were dose discrepancies measured with TLD, 5 were dose distribution discrepancies measured with radiochromic film and 12 were disagreements in both TLD and film measurements. There was a 38% discrepancy rate in first-time irradiations at the institutions with 3 or fewer machines and a 26% rate at the larger institutions. All of the institutions that failed multiple times were smaller institutions. **Conclusion:** Institutions of all sizes are capable of making mistakes in IMRT treatments. Sufficient physics coverage is an important aspect of IMRT quality assurance. **Conflict of Interest:** The investigation was supported by PHS grants CA10953 and CA81647 awarded by the NCI, DHHS.

SU-FF-T-149

IMRT Pre-Treatment Verification with Ionization Chamber, Film and EPID: Quality Vs. Time Consumption

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Purpose: The objective of this study was to obtain a standard IMRT pre-treatment verification protocol based on both quality and time-consumption parameters. A further objective was to define pass/fail criteria for the protocol. **Method and Materials:** Three existing pre-treatment verification methods were compared. 1) Total plan dose verification in a PVC slab phantom with an ionization chamber. 2) Total plan dose verification in PVC slab phantom with Kodak EDR2 film. 3) Single beam dose verification with the Siemens Optivue 500/1000 EPID. A prostate and head and neck plan were made with the XiO 4.2 IMRT TPS to evaluate quality (reproducibility and potential to detect significant errors) and time-consumption for each method. To evaluate reproducibility the plans were measured 10 times. The potential to detect errors was measured by introducing errors in the delivery by changing the number of monitor units, deletion of segments and MLC misalignment. For the time-consumption, measurement and analysis time were registered. A MATLAB tool was written to perform the analysis. Use of the gamma-index with different values for the dose difference percentage and distance to agreement was evaluated for methods 2 and 3. For the single beam dose verification method an additional criterion was defined and evaluated. This criterion was a combination of the mean percentage dose difference in a beam and the beam weight dependency. **Results:** The MATLAB tool provided a fast and accurate way to analyse the measurements. We were able to show clear differences between the three methods. As expected film verification was the most time consuming method and EPID verification could be performed the quickest, but still with high quality, i.e. reproducible and correct error detection. **Conclusion:** A comparison between the three methods resulted in the definition of a standard IMRT pre-treatment verification protocol with a favorable quality/time-consumption ratio and suitable criteria.

SU-FF-T-150

In Vivo Diode Dosimetry for Helical Tomotherapy Dose Verification

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Purpose: We propose and assess the feasibility of *in vivo* diode dosimetry for helical tomotherapy treatments. We aim to evaluate the influence of treatment parameters (grid size, field width, pitch and modulation factor) on diode measurements. **Method and Materials:** Isorad-p type diodes were calibrated and diode characteristics (angular dependence, etc) were studied. Treatment plans with different delivery parameters were performed on a s30 cm diameter solid water cylindrical phantom to deliver: 1) homogeneous dose to the whole phantom target; and 2) dose to a small target located at the center of the phantom. Diodes were placed in various positions at the surface of the phantom. The megavoltage CT (MVCT) was utilized for accurate phantom and diode localization. Diode measurements on patients have been performed and will also be analyzed. **Results:** Diode directional dependence in the transverse direction was less than ± 1% over full 360º rotation. On the whole phantom target, in general measured data were within ± 5% of the planned dose. Use of a fine dose grid (2mm) in planning generally showed better agreement with measurements. Field width has no effect on diode response. Higher pitch resulted in poor agreement. Diode measurements were within 10% of expected dose for a centrally located small target. Dose measurements for patients have been within 10% of expected dose. **Conclusion:** Isorad-p type diodes agree to ± 5% for some situations and better than ± 10% for in vivo diode dosimetry for helical tomotherapy treatments. A basic understanding of the effects of physical factors (field width, pitch and modulation factor, grid size) on variations in diode response is essential to select the accepted limit. In vivo dosimetry can be very useful as a secondary check for complicated helical tomotherapy radiation delivery.

SU-FF-T-151

In-Vivo Diode Dosimetry for IMRT Treatment Dose Verification

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Purpose: To investigate how diodes respond to various IMRT beam conditions and to evaluate the feasibility of using in-vivo diode dosimetry for IMRT treatment delivery verification. **Method and Materials:** A series of dynamic MLC files were created to simulate IMRT fields. Diodes and a Farmer chamber were used to measure IMRT doses at dmax in a phantom. Dose dependence on field size (FS), sliding window MLC leaf gap width, SSD and energy was investigated. In-vivo diode dosimetry was also used for patient IMRT treatment dose verification and compared with IMRT plan calculations. **Results:** Measured doses decreased with decreasing FS and MLC leaf gap. Diode readings agreed with ion chamber at dmax to within 3%. All measured data points were fitted to a straight line of "Measured Dose" vs. "%Primary Beam", with a slope of 0.945, intercept 0.04 cGy/MU, and correlation coefficient 0.997. For a given FS and leaf gap, measured doses increased with decreasing SSD. SSD dependence for ion chamber agreed with Inverse Square Factor (ISF) to ~1%. Diode SSD dependence deviated ISF by 1~4%. **Conclusion:** In measuring IMRT dose at dmax in phantom, diode readings agreed with ion chamber to within a few percent. Diode correction factors for SSD, FS, leaf gap, and energy dependence in IMRT treatment fields are small. Our study has shown that diode dosimetry can be used for in-vivo patient IMRT treatment delivery verification. In most cases, in-vivo diode measurements and IMRT plan calculations should agree to within ±7%. It is important to select a low dose gradient region from IMRT plan for diode placement. Larger discrepancies between measurements and calculations usually can be attributed to high dose gradient, errors in patient setup and diode positioning, and SSD change.

SU-FF-T-152

Independent Dosimetric Validation of Novalis IMRT and Dynamic Conformal Plans Using PHILIPS Pinnacle3Treatment Planning System

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Purpose: To study and validate the calculated dose distributions generated from Novalis inverse treatment planning system using PHILIPS Pinnacle^3 treatment planning system. **Method & Materials**: A total of 60 clinical Novalis plans comprising of 41 Dynamic Arc and 19 IMRT plans were selected in this study. The CT images for the individual cases were exported to Pinnacle^3 treatment planning system via network. A software script was developed to extract beam segments including MLC jaws, gantry, collimator and couch angles and monitor units from the RTP file generated by Novalis inverse planning system. The segmentation of MLC-based IMRT plans from Novalis system was imported into the Pinnacle^3 using the above software. The prescription and beam weights were set to reflect the treatment plan computed by the Novalis system. In all the above clinical cases, the dose distributions were computed and analyzed for homogeneous dose calculations. **Results:** The dosimetric results of all the above clinical cases have been analyzed. It was found that the agreement

between the two systems at the isocenter dose was 1.00 ± 0.028. In addition, the shapes of isodose lines in the three principal planes(axial, coronal and sagittal) were qualitatively agreed in both the systems **Conclusion:** This study helps in validating the Novalis IMRT and Dynamic Conformal plans on Pinnacle[3] which is well tested and documented on its convolution algorithm. These results indicate that the approach is robust and valuable for routine clinical IMRT plan validations as it takes account of entire clinical data set for the individual cases.

SU-FF-T-153

Influence of Ionization Chamber Size for Intensity Modulation Treatment Planning Modeling

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Purpose: Intensity modulation treatment planning systems (TPS) modeling requiere beam data collection of depth dose curves and dose profiles for open fields. The internal ionization chamber diameter is related with the width of the penumbra. The purpose of this work is to model a photon beam for Intensity Modulation Radiotherapy (IMRT) using two chambers with different sizes and compare the modeling results with film measurements using standard dynamic IMRT patterns. **Method and Materials:** The TPS used was CadPlan/Helios. The treatment energy used was 6 MeV generated by a linear accelerator Clinac 21EX equipped with a 120-leaf multileaf (MLC). The ionization chambers used were Wellhofer IC-10 (0.14cc) with internal diameter of 6 mm and a PTW Pint Point 31014 (0.015cc) with an internal diameter of 2 mm. Five standards IMRT patterns were used for comparisson. Grid calculation size was 2.5x2.5 mm^2 and 1.25x1.25 mm^2. To match calculated to film-measured isodoses, external MLC generated registration points were used. Measured isodoses were done using Kodak EDR2 film. Comparisson between calculated and measured isodoses were done by gamma evaluation (3mm/3% and 2mm/2%) using RIT113 software. **Results:** Measurements of dose profiles with Pint Point detector showed narrower penumbra (20%-80% penumbra width at 5 cm depth in water were 4.0 mm for the Pint Point chamber and 6.0 mm with the IC-10). Detector noise and measuring time increased with Pint Point chamber. Single pencil beam kernels generated from profiles measurements at 5 depths were sharper with the Pint Point detector. Agreement between calculated and measured isodoses was better with the smaller detector in all the standard IMRT patterns, especially at the high dose gradient regions. **Conclusions:** For CadPlan/Helios TPS, beam modeling for IMRT improves using an ionization chamber with smaller internal diameter.

SU-FF-T-154

Long-Term Reproducibility of IMRT Planning and Dosimetry Using Clinical Fields

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Purpose: To augment our patient-specific IMRT QA program by checking the individual and overall reproducibility of the DMLC planning and delivery systems periodically using standardized patient data sets and a commercial diode array. **Method and Materials:** Clinical fields were chosen from IMRT treatment plans using 6MV and 15MV, respectively. It is our intent to completely re-plan the same patients, generate leaf sequence files, and use the diode array to measure the absolute dose distributions for at least one different linac/MLC combination each month, thereby performing the evaluation for all MLC-equipped linacs every six months. The dose distributions are recalculated in a flat homogeneous phantom using the clinical treatment planning system. Data are analyzed using dose-difference and distance to agreement (DTA) methods. The supplied analysis program also provided a score for each field, which is defined as the percentage of the number of detectors satisfying the user defined dose-difference and dose threshold constraints and DTA constraint. **Results:** The scores for the fields used in this study range from 75-100% of an average ~200 points for each field for the 3% dose, 10% dose threshold, and 3 mm constraints that we specified. The diode array is able to identify the dose discrepancies relative to treatment planning calculations and earlier measurements and provides a quantitative score to grade each comparison, which along with the relative distribution of the failed points will serve as means for comparisons of measurements and/or calculations over time. **Conclusion:** The protocol that we present here enables us to provide a quick, accurate and reproducible evaluation of the overall DMLC planning and delivery process. With periodical evaluation using the same patients' data sets, we should be able to detect differences in performance among similar MLCs and linacs, and very small variations introduced over time for the same components.

SU-FF-T-155

Monte Carlo Dosimetric Verification for IMRT QA Using MLC Log Files and EPID

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Purpose: EPID is a useful tool for pre-treatment patient setup and target localization and post-treatment dosimetry verification. However, EPID images are significantly affected by photon attenuation and scattering in the patient and the detector and therefore cannot be used directly for dose reconstruction. This work investigates a Monte Carlo dosimetric verification method based on MLC log files and the electronic portal imaging device (EPID) for IMRT quality assurance (QA). **Method and Materials:** We have developed Monte Carlo based software to derive accurate intensity-modulated fluence maps behind the patient using MLC log files, which take into account the accelerator head geometry, the MLC leaf movement accuracy and the patient attenuation and scatter. Patient initial simulation and pre-treatment CT data were used to simulate the patient anatomy for interfraction dose comparison. The phase space data behind the patient were used in the EPID response simulation and compared with measured EPID images to investigate patient setup accuracy and dose reconstruction uncertainty. **Results:** Ten previously treated prostate IMRT plans and patient CT data are included in this study. The MLC leaf position accuracy of the dynalog files from a Varian 21Ex accelerator is verified to within 1mm. The dose distributions based on the leaf sequences from the treatment planning system and the fluence maps rebuilt from the dynalog files are consistent to within 2%, validating our software implementation. The primary photons and scatters are recorded separately behind the patient for different applications as described above. Energy spectrum, fluence distribution and angular distribution are derived to facilitate dose calculation in the EPID. **Conclusion:** We have developed a log file based Monte Carlo method to generate phase space and fluence maps for pre-treatment patient setup and post-treatment dose verification with EPID. This work is implemented as part of our IMRT QA procedure.

SU-FF-T-156

Multi-Institutional Retrospective Analysis of IMRT QA Measurements

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Purpose: To review IMRT QA measurements from several of the 50+ institutions for which we provide IMRT treatment plans and determine if institutional, anatomic site, or measurement biases exist. **Method and Materials:** For each patient receiving IMRT, the treatment plan is delivered to a solid water phantom and the dose measured using a small volume ion chamber and with a single EDR film placed 1 cm above the chamber plane. Of the almost 3000 IMRT treatment plans calculated and delivered in 2004, more than 1000 random, de-identified plans were reviewed. Ratios of chamber/calculated and film-center/calculated doses were tabulated for six anatomic sites (breast, prostate, pelvis, head & neck, brain, and other). Film dose distributions were compared to calculations using one of several commercially available QA packages. **Results:** The institutions with the best results had average errors of less than ±0.5% (i.e. randomly distributed about zero) with standard deviations of 1.25-1.50%. A few centers had average errors and standard deviations approaching 3%, indicating a bias in which a systematic dose measurement error was found. Agreement between chamber and film center dose was also institution specific with the best results found for those centers that had the lowest errors compared to calculation. One institution had excellent agreement between chamber and calculation (-0.2±1.7%), but 2-3% lower film dose. Although exceptions were found, little variation in the agreement between chamber measurement and calculation occurred as a function of anatomical site. **Conclusion:** Since all treatment plans were calculated in one central location and many centers had excellent agreement between measurement

and calculation, it is likely that the higher errors were due to measurement technique rather than errors in the dose calculation. Error was not anatomic site dependent possibly due to the purposeful placement of the ion chamber in a region of relatively uniform dose.

SU-FF-T-157

Optimal Matching of 3D Film Dosimetry with Calculated Dose for IMRT Quality Assurance

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Purpose: To develop an optimal matching of the three dimensional film dosimetry with calculated dose for Intensity Modulated Radiation Therapy (IMRT) quality assurance **Method and Materials:** We have fabricated the 3D IMRT phantom which consists of the base frame (30x30x5 cm^3) and 12 acrylic plates (30x30x1cm^3). The EDR2 films were embedded in each plate for 3D film dosimetry. Both absolute point dosimetry and 3D film dosimetry were performed throughout the IMRT using Clinac 21EX's millennium MLC. With custom-written software modules, the measured and calculated dose distributions for axial, coronal and sagittal planes were superimposed by coincidence of their origins, followed by comparison of the point doses at all matched positions. Then, with the optimization algorithm the setup errors were recovered. **Results:** We developed custom-written software modules for managing dose-distribution files, optimizing the position, calculating dose differences, and printing out the report. The dose verifications for axial, coronal and sagittal planes were obtained and graphically shown. Differences between the calculated and measured doses over the 3% criterion could be reduced by 15% after applying the optimization algorithm. **Conclusion:** We have presented a 3D dose-verification scheme with an optimization algorithm for IMRT that determines the setup errors in the measuring device by minimizing the average dose difference between the calculated and measured doses. Optimization dramatically reduced the difference between measured and calculated dose distributions in all cases investigated. **Conflict of Interest:** This investigation was supported by a research grant from the National Cancer Center, Korea (no. 0410310).

SU-FF-T-158

Optimized Sampling Pattern for Step and Shoot IMRT QA with a Diode Array

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Purpose: Diode arrays with sparse detector density are now widely used for IMRT QA. The goal of this work is to quantify and optimize the sampling of dose maps prior to the measurement in order to insure optimum sensitivity to potential delivery errors. **Method and Materials:** The diode pattern was first overlaid with the dose map and the fractional area sampled by at least one diode was separated into low and high gradient regions. The area sampled by a diode depended of the local dose gradient, which should not exceed a user-defined threshold. The number of leaf and jaw positions sampled by at least one diode was also obtained from the area of gradient sampled and the known segment shapes. The dose map and the collimator sampling were optimized using a simulated annealing algorithm to select the position of the diode array in the beam. The sampling improvement with multiple measurements at optimized detector positions was also studied. **Results:** For a 7 beam head and neck IMRT plan and the diode array centered on the central axis, the average fraction of the high and low gradient regions sampled at least by one diode was 13.9% and 79.6% respectively. In average, 85.8% and 83.5% of the leaf and jaw positions were sampled with a minimum reaching 58%. The optimization of the detector position improved the collimator sampling to more than 94% for all beams. The use of two array positions per beam improved the sampling in the high gradient areas. **Conclusion:** This method allows to identify the beams for which conventional diode array sampling would be suboptimal. The optimization of the detector position and the number of measurements insure adequate sensitivity to delivery errors related to dose and collimator calibration. **Conflict of Interest:** Supported by Sun Nuclear Corporation.

SU-FF-T-159

Patient Quality Assurance Analysis for Tomotherapy

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Purpose: IMRT plans developed for conventional Linac equipped with dynamic MLC can be independently verified using a number of commercially available software packages. For the HiArt TomoTherapy unit however, the only dose verification mechanism is by measurement. The purpose of this investigation is to analyze the patient specific quality assurance results for the HiArt TomoTherapy intensity modulated radiotherapy treatment planning and delivery system in our clinic. **Method and Materials:** We have developed a systematic patient specific IMRT QA program that was implemented in April of 2004. 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. Film calibration is performed daily using an in-house developed protocol and software tool. Dosimetric analysis is performed after the film and planar dose are co-registered in the TomoTherapy planning station. In total, 63 patients were analyzed. **Results:** Dosimetric analysis was performed based on both film and ion chamber measurements. The median and mode discrepancy is below 2% for the point measurements. Similar results are found for the film analysis which provides not only absolute dosimetry but also isodose distribution and profile comparison between measured and calculated planar dose distributions. The plane and points of calculation can introduce small errors in the analysis. **Conclusion:** A comprehensive patient QA program has been developed and the results of 63 patients 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 2%.

SU-FF-T-160

Patient Specific QA for Prostate and H&N IMRT Using MapCheck

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Purpose: To evaluate the MapCheck system as a device for routine IMRT QA. **Method and Materials:** 20 prostate and 2 nasopharyngeal cases are used for this study. IMRT treatment planning was performed with Varian Eclipse/Helios planning system using sliding window technique. The measured dose distributions (both absolute and relative) are compared with the generated ones from the planning system. **Results:** For prostate IMRT QA, the measured dose distribution agrees well with the calculated ones by using a 3% difference and 3 mm distance to agreement (DTA), 10% threshold criteria. The pass rate is over 90% (20 cases) for both relative and absolute dose comparison. For nasopharyngeal head & neck IMRT, the relative pass rate is over 90%, while the absolute pass rate is around 40-60% by using a 5% difference and 3 mm DTA. Most of measured points are 5-10% higher than planned in the absolute comparison. In addition, we made ion chamber point dose verification measurements at carefully selected points in the relatively low dose gradient area at the same gantry angle of each beam as delivery of the treatment. Chamber measurement results have shown an agreement of within 3% in total dose compared to the calculated ones. **Conclusion:** Our clinical experience shows that MapCheck device works well for prostate IMRT QA, for both absolute and relative dose verification, which dramatically increases our IMRT QA efficiency. However, from the preliminary work from our 2 nasopharyngeal head & neck IMRT cases, the measured dose by MapCheck appears to be 5-10% higher than the planned dose for most points, while the relative dose map matches well with the planned data (with criteria 10% threshold, 5% difference, 3mm DTA) which is inconsistent with ion chamber measurements. The discrepancy is under investigation.

SU-FF-T-161

Practical Gap-Width Threshold for MLC Quality Assurance for IMRT

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Purpose: A standard IMRT quality assurance test for Multi Leaf Collimator (MLC) leaf position accuracy is the Memorial Sloan-Kettering (MSK) leaf test. This test involves inspecting the widths of five 1 mm wide fields delivered 2 cm apart. A maximum error tolerance of 0.2 mm in the gap-width between sets of opposing leaves is recommended. In a preliminary informal visual test performed with an independent observer, the observer detected all deliberately introduced errors greater than or equal to 0.5 mm, but not all 0.2 mm errors. **Method and Materials:** We investigated the use of the MSK leaf test on a Varian Clinac 2300C/D and Clinac 2300EX, with Mark I (52 leaf) and Millennium (120 leaf) MLCs, respectively. Kodak XV film was irradiated with 6 MV photons at an SSD of 100 cm, using 1000 monitor units for the delivery of the five segments. The film was scanned using a Vidar VXR-16DP scanner, and subsequently analyzed with the RIT113 Version4 software. The RIT software recommends using a 3x3 median filter to remove background noise, which effectively reduces the image resolution. Since the smallest baseline resolution of the scanner is 0.089 mm, a 0.2mm error will be difficult to observe after a 3x3 filtration. Separate films were irradiated under the same conditions and scanned to determine if the scanner software combination was consistent in assessment of the magnitude of errors in the gap-width. **Results:** The reproducibility of leaf positions on multiple films was found to be within one pixel. However, not all artificially introduced errors that were visually observable were detected by this software technique. **Conclusion:** It may not be feasible to reliably measure gap-width errors of 0.2 mm, either by eye or by quantitative analysis using the technique presented here.

SU-FF-T-162

Quality Assurance for a Tomotherapy Machine: New Procedures and Comparison to TG-40 Recommendations for Conventional Linear Accelerators

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Purpose: To compare daily and monthly quality assurance, QA, procedures on a TomoTherapy machine with TG-40 recommendations for a conventional linear accelerator. **Method and Materials:** A commercially available diode check-unit is retrofitted for use in daily and monthly TomoTherapy QA. Output consistency is checked with this unit. The housing of the check unit is equipped with 1-mm diameter lead markers that provide for checks of megavoltage CT imaging, laser alignment, and couch motion. On a monthly basis more quantitative checks of laser alignment, beam energy, beam profiles, and couch motion are done with a diode array. A very efficient test procedure has been developed that uses this array. **Results:** On a daily schedule**,** output consistency, laser alignment, and couch motion are check with a single measurement that takes approximately 10 minutes. Daily output checks over 118 days of operation show the output to vary with a 1-standard deviation of 2%. Based on megavoltage imaging of the morning check unit, the vertical and superior-inferior green-laser alignment and couch motion are found to vary by less than 1 mm. In this time period, the left-to-right green-laser drifted past a 2 mm limit and adjustments were made to correct the alignment. On a monthly schedule absolute beam output was measured for 1, 2.5 and 5.0-cm jaw widths and found to vary by ±1%. Beam energy shifts were found to be ±1.2%. Monthly comparisons to commissioning profiles indicate small changes in the left-to-right direction, which are indicative of small changes in beam energy. **Conclusion:** New procedures and tolerances had to be developed for daily and monthly checks of the TomoTherapy unit. Over a five month period the machine stability has been acceptable. Many TG-40 checks for conventional linear accelerators are not applicable to a TomoTherapy machine.

SU-FF-T-163

Quantitative Verification of IMRT Intensity Maps Using An Amorphous Silicon Electronic Portal Imager

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Purpose: Common quality assurance procedures for intensity modulated radiotherapy include ionization chamber and/or film measurements in phantom for comparison with point doses and dose distributions predicted by the treatment planning system. We have developed a method to quantitatively compare individual intended fluence maps with measured intensity distributions using an aS500 amorphous silicon electronic portal imager (EPI). **Method and Materials:** A software program recognizes the intensity map and extracts the intensity in each bixel relative to the maximum bixel value. A simple single-bixel scatter model was applied to account for scatter in the imager. The software quantitatively compares normalized bixel values in the EPI intensity map with the fluence map exported from the Corvus treatment planning system after correction for scatter. **Results:** Applying the scatter correction reduces the deviation between EPI maps and planned fluence maps, decreasing the correlation coefficient from 0.59 to 0.24. For 14 gantry angles and a total of 1663 bixels, we compared EPI intensity maps with scatter-corrected planned fluence maps. The mean error was 1.0% ± 4.1% (1σ) with scatter correction, and 2.4% ± 4.9% (1σ) without scatter correction. Our clinical intensity maps utilize ten intensity levels. When rounded to the nearest intensity level, 69% of all bixels agree with the predicted intensity level, while 99% of bixels are within 10% of the predicted intensity. The majority of bixels in disagreement have low intensity. The mean error for bixels with a planned relative intensity of 10% was 6.3% ± 5.2%. **Conclusion:** Future refinement of the normalization and scatter correction methods will improve agreement in the low intensity bixels. This would improve the sensitivity of this tool and potentially allow it to replace the more time consuming film and ionization chamber techniques commonly used for IMRT quality assurance.

SU-FF-T-164

Radiochromic EBT Film Characterization and Applicability for IMRT QA Verification

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Purpose: Characterization of ISP's new EBT radiochromic film for clinical dosimetry, with emphasis on the usefulness for routine QA of IMRT treatments. **Method and Materials:** EBT is a new formulation of radiochromic film by ISP. Sheets were exposed to 6 MV and 18 MV photons from a Varian 2300C/D accelerator over clinically useful dose ranges. Density was measured by scanning the film in a Vidar VXR-16 Dosimetry Pro scanner and the data analyzed using RIT113 v4 software. The reproducibility, stability, and temperature sensitivity were investigated. Dose distributions for IMRT treatments delivered with a Millinieum 120 leaf MLC were measured with the EBT film and compared to those of Kodak EDR2 film and to the predictions of the Eclipse treatment planning system. **Results:** EBT films from the same batch have a consistent response to doses ranging from 50 to 500 cGy for 6 MV and 18 MV photons. The density readings are stable from 1 to 75 hours post exposure when stored in the dark at room temperature. Beyond 75 hours, the density slowly increases. The film is insensitive to cold, but shows significant degradation when exposed to 60 C for as little as two hours. For IMRT dose distributions where the dose is below 200 cGy, the EBT film has similar responses as Kodak's EDR2 film and very close agreement to the Eclipse predictions. In regions of IMRT doses greater than 200 cGy, the EBT film loses sensitivity as compared to EDR2 film and to the Eclipse calculations. **Conclusion:** ISP's EBT radiochromic film is reproducible and stable under normal clinical conditions. For IMRT dose verification, the EBT film is in close agreement with calculations and EDR2 film for doses less than 200 cGy. Further research is needed to understand the reduced response of EBT to IMRT doses above 200 cGy.

SU-FF-T-165

Replacement of Film and Ion Chamber Measurements by Electronic Portal Dosimetry for IMRT QA

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Purpose: To evaluate replacing film and ion chamber measurements with EPID portal dosimetry for IMRT QA. **Method and Materials:** IMRT plans are generated in commercially available planning software and a prediction for each field is generated for a square solid water phantom (with the gantry set to 0 deg), a bullet phantom and an aSi EPID. Each IMRT field is delivered to the solid water phantom exposing individual radiographic films. A high dose region and critical structure region is identified in the bullet phantom predicted dose distribution. The IMRT fields are delivered to the bullet phantom with an ion chamber at the high dose region, and repeated with the ion chamber at the critical structure region. The IMRT fields are then delivered to the EPID and a dosimetric image is obtained using commercially available software. The dose delivered to the film is analyzed and compared with the prediction. The ion chamber measurements are compared to the prediction in the bullet

phantom. The EPID prediction vs. acquired portal dose is analyzed. EPID results are compared to film and ion chamber results to determine if the EPID can be used as a replacement for film and/or the ion chamber measurements. **Results:** Preliminary results indicate that the EPID with commercially available portal dosimetry software has a high dosimetric sensitivity, in the range of 1 to 2 cGy, and sub millimeter special resolution. This is suitable for film replacement. **Conclusion:** The EPID with commercially available portal dosimetry software can be used as a replacement for film given proper calibration of both the imager and software model. Further research is being done in order to determine if the ion chamber measurement can be similarly replaced. **Conflict of Interest:** Varian Medical Systems partially funded this research.

SU-FF-T-166

Reproducibility Of A Method For The Quanitative Assessment Of The Agreement Between Planned And Measured Dose Distributions

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Purpose: To introduce a new quality assurance parameter, the index of agreement (IOA), with which to quantify the agreement between planned and measured radiation dose distributions, and to assess the reproducibility of the parameter. **Method and Materials:** One IMRT radiation portal, consisting of three segments, was used to irradiate twenty separate pieces of calibrated EDR film. The field was delivered with a Siemens PRIMUS linear accelerator with 10 MV photons. A planar dose file was generated with the ADAC Pinnacle RTP system at a resolution of 2 mm by 2 mm to represent the dose distribution of the field. Both the planar dose file and the measured dose distributions derived from the film were imported into MATLAB for processing and analysis. At each pixel of the planned dose distribution, the pixel of the measured dose distribution, within a closed neighborhood of radius c (chosen to be 3 mm) that exhibits the smallest absolute fractional dose deviation was found. If the absolute deviation was less than p% (chosen to be 3%), the pixel was assigned a score of zero, while if the absolute fractional deviation exceeded the tolerance value, the pixel was assigned a score of zero. The index of agreement (IOA) was then calculated as the ratio of the sum of the score values of all clinically relevant pixels divided by the total number of clinically relevant pixels. **Results:** The IOA values were approximately normally distributed, with a mean value of 0.9330 and a standard deviation of 1.1%. Areas of poor agreement were reproduced during each irradiation. **Conclusion:** The IOA is a promising new quantitative quality assurance tool, and its value is highly reproducible.

SU-FF-T-167

Systematic Approach for Predicting DMLC Motor Failure: A Prognostic Strategy

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Purpose: Dynamic MLC and segmental MLC are the two competing delivery modes for IMRT plans. Each has its merits and limitations. Dynamic MLC provides a higher temporal resolution and more accurate dose delivery. However, it exerts extra stress on MLC driving motors, leading to a high motor failure rate. This stems from frequently alternated leaf acceleration and deceleration. The excessive heat generated by high instantaneous torque of the driving motors eventually leads to motor failure. This is particularly true for complicated head and neck cases, where many irregularly-shaped critical structures are involved and steep dose gradients are required. Frequent machine down-times create serious logistical problems and delay patient treatment. In this study, an attempt was made to decipher the DMLC motor failure pattern and design a practical prognostic strategy. **Method and Materials:** A new VARIAN CLINAC 21EX was installed in our center in June 2004. Each evening, a "stress-test" DMLC file was run at gantry angles 0°, 90°, 180°, and 270°. This procedure was repeated after MLC reinitialization. All Dynalog files recording the leaf positions were saved for postprocessing. The "stress-test" file was created to intentionally "exercise" the leave at high speed so that those "sick" leave could be identified. The Dynalog files were then analyzed using ARGUS IMRT software. Based on our past seven months' data, a prognostic most probable motor failure threshold was established. **Results:** The motor failure patterns in terms of leaf position RMS errors were diverse, complicated, and disease site specific. An RMS value of 0.15 cm could be a good prognostic index for potential motor failure. However, "false positive" cases could still occur. **Conclusion:** The prognostic strategy presented here is practical and easy to implement. However, a large sample of failed motors is needed to further validate the established threshold.

SU-FF-T-168

The Evaluation of Several Commercial IMRT Treatment Planning Systems Heterogeneity Dose Calculation Algorithms Using An Anthropomorphic Thorax Phantom

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Purpose: To measure the accuracy of heterogeneity dose calculation algorithms from several commercial IMRT treatment planning systems using an anthropomorphic thorax phantom. **Method and Materials:** Four planning trials were designed to characterize heterogeneity dose calculation algorithms. The four trials were 1) evaluation of ADAC Pinnacle's conventional 3D algorithm as a baseline, 2) evaluation of Pinnacle IMRT, 3) evaluation of Corvus IMRT and 4) evaluation of a hybrid plan consisting of the Pinnacle dose calculation optimized by Corvus. The accuracy of the algorithms was determined by delivering the clinically relevant treatment plans to the Radiological Physics Center's anthropomorphic thorax phantom. The phantom contained radiochromic film in the three major planes and TLDs in the center of the tumor target. The film data were normalized to the TLD readings. Point doses and planar dose distributions were extracted from the treatment planning system and compared to TLD and film measurements. Dose profiles and planar dose distributions were compared point by point using criteria of ±5% and 3mm distance to agreement. **Results:** Preliminary results for Pinnacle reveal TLD-to-calculation dose ratios of 0.994 and 0.990 for 3D and IMRT, respectively. Points on dose profiles through the target and adjacent lung met the agreement criteria 96% and 84% of the time for the respective treatment techniques. The 3D TPS planar dose distribution agreed with measurements to within the criteria at 74% of the points, while the IMRT TPS agreed at 73% of the points. **Conclusion:** The Pinnacle conventional and IMRT heterogeneous dose calculation algorithms agree well with measured data in an anthropomorphic thorax phantom.

SU-FF-T-169

The Use of Diode in In-Vivo Dosimetry Quality Assurance in IMRT

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Purpose: In IMRT treatments, the ultimate QA procedure is to carry out in-vivo dosimetry measurement to ensure the accuracies of both patient setup and beam delivery. This study was designed to explore the use of in-vivo diode dosimetry measurement for QA of IMRT treatments.
Method and Materials: IMRT plans were generated based on a set of CT scans of a head & neck anthropomorphic phantom. Corresponding IMRT QA verification plans were also generated. Diode calibration readings (R_c) were obtained for each beam during the routine dose verification QA process. During verification, a diode was placed along the beam central axis on the surface of a flat QA phantom at the SSD specified in the QA plan. Radiation was delivered dynamically using the same dynamic MLC files that were to be used for the patient treatment. For in-vivo measurements, the anthropomorphic phantom was setup according to the treatment plan. For each beam, a diode was placed along the central axis at the beam surface entry point. Radiation was then delivered according to the plan and the diode reading (R_i) was recorded. If both the setup and the beam delivery were correct, R_i should be in agreement with quantity $R_c * f_{SSD}$ within certain uncertainty (f_{SSD} is SSD correction factor); otherwise, it would be an indication of incorrect patient setup or incorrect beam delivery. **Results:** It was found that the calibration diode readings followed the SSD inverse square law within an uncertainty of 0.4%. $f_{ssD} = \left(\frac{SSD_c}{SSD_i} \right)^2$. The derived in-vivo diode readings ($R_c * f_{SSD}$) were in agreement with those measured ones within 3.6% for three beams at different gantry angles, with an average difference of 1.8%.

Conclusion: With a proper calibration method, diode verification can be used relatively accurately for in-vivo measurements to check on the accuracies of patient setup and beam delivery for IMRT treatments.

SU-FF-T-170

Tomotherapy Daily Quality Assurance Phantom

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Purpose: To present a phantom specifically designed for daily quality assurance measurements of the radiation beam characteristics of the tomotherapy Hi-Art machine over a large angular range of the beam. **Method and Materials:** The phantom is made out of solid water carved in the shape of two co-axial hemi-cylinders with two different radii, and the same depth. The radii are chosen to be 5.0 and 10.0 cm. The depth of the phantom is chosen to be 6.0 cm. The two hemi-cylinders are supported on top of a 16.0 cm high stand also made out of solid water. A hole along the phantom's central axis accommodates a PTW ion chamber which is connected to an electrometer for current or charge reading. A delivery plan utilizing the synchrony between the MLC and the gantry rotational speed is specifically designed to run while the phantom is placed at the machine isocenter. The electrometer reading can be manually or automatically entered into a computer program that will calculate the instantaneous or average rotational output and energy consistency of the machine. **Results:** When collecting the current from the electrometer, six output reading segments (each segment covers 120 degrees) at two different depths, can be collected in six minutes. If the electrometer is setup to collect charge, six output readings will be collected; each reading is the cumulative charge from 120 degrees of the rotational beam. **Conclusion:** Using this phantom, daily quality assurance of the Hi-Art Tomotherapy machine can include measurements of the consistency of rotational output, rotational beam energy, gantry rotational speed, and MLC synchrony with the gantry speed all packed within on six-minute procedure.

SU-FF-T-171

TomoTherapy HI-ART Heterogeneity Calculations

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Purpose: To examine the accuracy of the TomoTherapy HI-ART® treatment planning system's dose heterogeneity algorithm. **Method and Materials:** The TomoTherapy HI-ART® treatment planning system uses the superposition/convolution dose algorithm for calculating heterogeneous dose distributions. To evaluate the combined delivery and dose calculation of this system, a series of treatment plans and corresponding measurements were made with: (1) calibrated CT density plugs and embedded TLD (2) film phantom and calibrated CT density plugs, (3) anthropomorphic phantoms containing TLD and film, and (4) different phantom materials with chamber inserts. Treatment plans were delineated with one cylindrical target calculated with homogeneous dose distributions at 60 Gy (1 Gy/fx, S.D. < 0.7). **Results:** The film studies using the film phantom show that the predictions are within 5-10 % along the interface and within the heterogeneity materials. TLD values using embedded plugs in various phantoms indicate comparable agreement. Phantoms with slab materials, composed of electron densities within 10% of water, are within 5% between calculations and ion chamber measurements. The lung phantom indicates that the readings agree with predictions to within 4%. **Conclusion:** The heterogeneity calculations agree with measurements to within 10%. Film measurements demonstrate more variability and discrepancy than the other measurements. The interface measurements demonstrate the largest disagreement where the dose gradient is approximately 10% for a uniform dose calculation between two different electron density materials.

SU-FF-T-172

Verification of Whole-Body Dosimetry in An IMRT Treatment Planning System

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Purpose: IMRT has been widely used in radiation therapy, since this technique shows potential for further improving the therapeutic ratio and reducing complications. On the other hand, it has been suggested that IMRT presents a potential impact on the induction of second malignancies, because it can result in a higher whole-body dose due to leakage radiation. In the routine treatment planning process, complete information on the whole-body dose-volume histogram is not available due to the limited patient body volume imaged in the CT treatment planning process. In addition, for IMRT, larger volumes of normal tissues are being exposed to low doses, and the dosimetric uncertainties of a treatment planning system at these doses are relatively large. In this study, whole-body dosimetry calculated from the Eclipse-Helios planning system was verified using a whole-body anthropomorphic phantom and MOSFET detectors, as well as polymer gels. **Method and Materials:** The "ATOM" whole-body anthropomorphic phantom was CT- scanned into the Eclipse-Helios system. An IMRT prostate plan was designed for the ATOM phantom. Each MOSFET detector was calibrated at various angles based on ion chamber dosimetry. The MOSFET detectors were precisely placed in relocatable dosimeter positions corresponding to various internal organs, allowing point-dose measurements and comparison. BANG® polymer gel, prepared in a cylindrical container, was placed at the phantom head position to measure the 3D dose distribution. The DVH in the gel cylinder, analyzed with an optical CT scanner, was compared with that from the planning system. **Results:** Preliminary results show that the agreement between the MOSFET measurements and the calculated results is within 5% for points within the target. At low-dose regions (0.1-60%), discrepancies are larger but reasonable. DVH comparison between gels and the treatment planning will be presented. **Conclusion:** Anthropomorphic phantom with MOSFET detectors and polymer gels can provide whole-body dosimetry verification for IMRT.

SU-FF-T-173

A Comparison of Techniques for Effective SSD Measurements and Evaluation of Data for Accelerators From Different Manufactures

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Purpose: Investigating and comparing the effective SSDs of electron beams measured by ionization chamber and electron diode for Elekta linear accelerators. **Method and Materials:** The effective SSDs for different energies and field sizes are measured for three Elekta linear accelerators. In order to measure effective SSD (SSD_{eff}), two methods are used. The first method is placing a Farmer ionization chamber in a solid water phantom. The second method is using an electron diode placed on top surface of a solid water phantom. **Results:** The data shows that effective SSDs are energy and insert field size dependent. For both ionization chamber and electron diode measurements, the effective SSDs of three Eleckta linear accelerators, 1) increase with increasing of energy and insert field sizes which can be explained by less lateral scattering with higher energy and more lateral scattering equilibrium with lager field sizes, 2) agree well between the ionization chamber and diode measurements except for under the combinations of low energy and small field size. In most cases, the diode measurements are about 8 to 12 percent lower than ion chamber measurements for the same energy and insert field, except low energy and small insert combinations. Interestingly, for small field size, the effective SSD of diode measurement is larger than that of ion chamber measurement. **Conclusion:** The effective SSDs of three Elekta Linear accelerators agree well under most conditions except low energy and small insert field size combinations. The data also indicate that ion chamber measurements give a more accurate measurement over diode measurement and we recommend that ionization chamber should be used to measure effective SSD. The data also show that effective SSDs for Eleckta accelerators are different but comparable to that of Varian machines.

SU-FF-T-174

A New Device for the Verification of Temporal Function of the 4DCT and Gating Delivery System

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Purpose: A quality assurance device was developed for 4DCT (GE Medical System, Waukesha, Wisconsin) and the Real-Time Position Management Respiratory Gating System (Varian Medical Systems, Palo Alto, CA). It verifies the temporal-phase function of the 4DCT and the gated delivery function of the Linac. **Method and Materials:** The QA device is composed of a mobile phantom, static phantom, acrylic lobe, AC motor, power transformer and transmission mechanism. There are eight

radio-opaque lines embedded in the static phantom, which are used as reference indicators. A "Z" shape radio-opaque marker is fixed on the top of the mobile. This phantom moves periodically with a maximum displacement of 3 cm in a horizontal direction. It was scanned under our 4DCT at a period of 5 seconds. The collected images were divided into 10 groups representing 10 phases of the moving cycle. The digitally reconstructed radiograph of each phase was generated for the verification of the temporal-phase function of the 4DCT. To verify the gated delivery function of the Linac, a radiographic film was attached to the surface of the mobile phantom and a 0.5 cm by 10 cm X-ray field was used to expose the film at certain phases. The expected position of 0% phase was marked by punching 2 small holes on the film. **Results:** The "Z" mark was correctly shown and aligned with the reference lines at each phase. The film exposed under the Linac has shown that the radiation had been delivered to the correct position. **Conclusion:** A reliable quality assurance device for 4DCT and respiratory gating system is necessary to ensure that the radiation dose is accurately delivered to the patient's target volume. This QA device is effective and convenient for checking temporal-phase function on the 4DCT and RPM gating system.

SU-FF-T-175

A New Linac QA Procedure for the Characterization of Gantry Radiation Isocenter

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Purpose: A new linac QA method is developed to characterize the size and shape of gantry radiation isocenter. The method accurately measures gantry sag as a function of gantry angles and the size of gantry radiation isocenter in the gantry rotation plane. **Method and Material**s: In order to determine both sag and radiation isocenter size in the gantry rotation plane we wrap a film (or a phosphor imaging plate) on a cylinder of circumference equal to the film length. We designed a static MLC "dashed line" pattern consisting of regions of radiation along a line. The pattern is designed such that the center of the irradiation line can be easily determined.

The cylinder is positioned such that its axis is the same as the gantry rotation axis. The film is exposed to the MLC line pattern for multiple gantry angles. Both entry and exit patterns are seen on the film. A special MLC pattern was designed to accurately characterize the gap between the two ends of the film.

An automated analysis program determines the MLC line angles and centers on the film, characterizes the cylinder position and generates the desired gantry radiation isocenter information. **Results:** The gantry sag is observed to have a smooth dependence on gantry angle with extreme values for 0^0 and 180^0. The smallest circle crossing or tangent to all rays in the gantry rotation plane determines the gantry radiation isocenter size in this plane. The inherent accuracy of the method is estimated at +/- 0.1 mm. The total irradiation time is about 15 min. The data analysis is less than 5 min. **Conclusion:** The designed method characterizes both gantry sag and wobble in one simple and accurate test.

SU-FF-T-176

A Shielding Design for a High-Energy Doorless Accelerator Vault

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Purpose: To design three doorless vaults capable of accommodating high-energy accelerators of at least 16 MV. This design must meet the state of Michigan standards currently set at 250 μSv per year for an uncontrolled area, and 5,000 μSv per year for a controlled area. Furthermore, the design must occupy a footprint similar to traditional vaults with shielded doors. **Method and Materials:** Standard calculation protocols were used to calculate various thicknesses of shielding materials in the walls and the ceiling. We used commercial interlocking bricks in densities of 240 lb/cf and 288 lb/cf. Additional shielding materials used were steel plates, lead plates, standard polyethylene and 5% borated polyethylene. The mazes consist of high-density brick (Ledite) and 5% borated polyethylene panels at various points. The mazes are 24 feet in length, 6 feet in width but are staggered to reduce the cross-sectional profile. The opening is 6 feet wide and is at 90^0 to conventional openings. The space adjacent to the vaults, including the floor above, is occupied and uncontrolled. Two Siemens Oncor and a TomoTherapy unit were used in this study. **Results:** We have carried out extensive measurements of dose equivalents at various points inside the treatment rooms as well as in the mazes, the walls, and adjoining areas. All areas comply with the state Michigan current standards. Annual equivalent dose at the opening of the rooms, using a workload of 59,000 Gy per year at 100% 16 MV, ranges from 200-2,000 μSv per year. **Conclusion:** This design indicates the possibility of achieving acceptable dose at the opening of a high-energy linear accelerator without a shielded door. This can be accomplished in a standard accelerator footprint. The doorless design enhances patient comfort, patient and staff safety, and is cost-effective.

SU-FF-T-177

A Study On Output Factors for Gamma Knife Model B2 Unit with Various Dosimeters

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Purposes: To verify the output factors (OFs) of Gamma Knife Model B2 by various conventional dosimeters and to determine an effective correction factor for compensating the dosimeter sizes. **Method and Materials:** The TLDs, radiochromic films, PTW 31002 ion chamber and the diamond detector were used to obtain the OFs, normalized to the 18 mm helmet, for four helmets. The factors were measured in the centre of an 80 mm polystyrene spherical phantom that was positioned at the mechanical center of the machine. The dosimeters were placed in the center of the sphere using different cassettes and oriented their effective center in the center of helmet coordinate system. Based on the volumetric averaging theory we used the specificity of dose profile of the 4 mm helmet to correct the measurement by the integrated Gaussian curve method. **Results:** The relative OFs measured with TLDs/ion chamber, before applying correction factors, were 0.977/0.967, 0.905/0.845 and 0.755/0.313 for the 14, 8 and 4 mm helmets, respectively. After applying correction factors, the results show a reasonable agreement with the data used in the current RTP system for Gamma Knife procedure. The results also showed great spatial accuracy. The symmetry of spatial distribution was 1.84%, 0.59%, 1.25%, and 1.16% for the 4, 8, 14 and 18 mm helmets, respectively. And the distance between mechanical center and dosimetric center was less than 0.25mm for all four helmets. **Conclusion:** The accuracy of the measurements was affected by a number of factors, especially the dosimeter size. This work provides the potential for using conventional dosimeters, with appropriate correction factor, to determine and to evaluate the clinical dosimetric parameters for Gamma Knife Unit for routine QA procedure. With the verification of spatial accuracy, Gamma Knife unit could be used to treat functional disorder case accurately.

SU-FF-T-178

A Study On the Reproducibility of Tangential Breast Fields Using Online Electronic Portal Images

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Purpose: To study the reproducibility of tangential breast treatment technique using online portal imaging system.**Introduction:** Treatment verification and reproducibility is an important step in radiotherapy to achieve a better tumor control. Care should be taken to ensure the same dose to be delivered in the same volume of irradiation. Electronic portal imaging technique plays a vital role in accomplishing the above task by studying the setup error and correct the same before the treatment delivery. **Method and Materials:** Twelve patients of carcinoma of breast were selected for this study and CT based planning was performed with simple tangential fields. The patients were then treated on a 6MV linear accelerator equipped with an electronic portal imaging device. Portal images were acquired for both medial and lateral tangential fields for 10 fractions and intra and the inter-fraction studies were performed for all the patients. The parameters such as central lung distance (CLD), Central beam edge to skin distance, central irradiated width and cranio-caudal distances were measured on the acquired portal image. In the intra-fraction study lead markers were placed on the patient skin to study the breast movement

during treatment. **Results:** The maximum variation of the marker during the treatment was 1.8 mm with a standard deviation of 0.575 mm. Similarly the CLD, CBESD, CIW and CCD were analyzed for the intra and inter-fraction variation. **Conclusion:** Online portal imaging device is an important tool for ensuring the proper delivery of planned dose. Our result suggests that intra-fraction motion of the breast has less impact on the treatment volume.

SU-FF-T-179

Accuracy of CT Numbers and Its Effect On Dose Calculations

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Purpose: The CT-to-density conversion table can vary for various CT scanners or when using different scanning parameters (such as KVp, field-of-view etc.). These CT number variations could be up to -/+100 for the same material. However, the dosimetric impact of these CT number variations was not well studied in the past. This study is to report the variations of CT numbers and their clinical impact on dose calculations. **Method and Materials:** The CT-to-density conversion table was measured on six different scanners. Two special tables were created with +/- 100 CT-number shifts from the default conversion table in our clinic. Data showed that these two tables represented two bounding situations to accommodate the variations in different CT scanners or scanning parameters. Treatment plans using lung, head and neck, prostate, and breast cases were recalculated using these new CT conversion tables for both photon and electron beams. **Results:** There were noticeable differences across different density ranges for different CT scanners. Using the two extreme CT-to-density conversion tables, it was shown that the differences in dose calculations were -1.6% to 0.3% for head & neck (6MV), -2.5% to 0.9% for lung (6MV), -4.0% to 3.0% for prostate (6MV), and -2.3% to 1.7% for prostate (18MV), respectively. It showed that the impact was more notable for treatment targets at deeper depths or at lower beam energy. For electron beams, the distal 90% fall-off edge was changed approximately 2 mm for commonly used electron energies. **Conclusion:** Dose calculations seem to be not sensitive to different CT-density conversion tables from different CT scanners or using different CT scanning parameters. Considering most scanners were calibrated to water, our results could be the worst case scenario. A single CT-to-density conversion table could be used for all CT scanners.

SU-FF-T-180

An Experimental Comparison of Whole-Body Photon Doses for IMRT and 3D-CRT

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Purpose: IMRT is a viable form of radiation treatment. As a new technology, however, IMRT techniques present many new challenges. The change from 3D-CRT to IMRT, for example, may result in an increase in second malignancies due to more fields and longer exposure times. Although NCI and others have identified this potential problem, there has been limited guidance. The goal of this study is to establish a method for comparing in-phantom measurement of whole body doses resulting from typical 3D CRT and IMRT treatment plans. **Method and Materials**: The measurements involved a RANDO phantom and MOSFET dosimeters. Three different treatment plans, 4-field 3D-CRT, 6-field 3D-CRT and 7-field IMRT for the prostate, were used for this study. The steps to re-construct organ doses using a physical phantom and MOSFET dosimeters are summarized in the supporting material. **Results**: The dosimeter readings show that the doses decrease as the distances increase for all treatment plans. At 40 cm from the target, the doses are reduced nearly 100%. At this location, however, the IMRT plan resulted in a dose that is a factor of 3-5 higher than the two 3D-CRT plans. This is due to the increased scattered radiation from the extended exposure time for IMRT case. The total monitor unit (MU) is 2850 for the IMRT case, while 1308 and 1260 for 6-field and 4-field 3D-CRT cases, respectively. **Conclusion:** A method has been developed and tested to use MOSFET dosimeters to measure and compare whole-body doses resulting from IMRT and 3D CRT treatment plans. The case study for prostate shows that the IMRT indeed delivers higher photon doses to locations that are away from the prostate target. On-going studies will use a whole-body VIP-Man model containing 80 segmented organs and Monte Carlo method to simulate various treatment plans for photons and protons.

SU-FF-T-181

An Investigation of Surface Dose Changes for Therapeutic Kilovoltage X-Ray Beams with Underlying Lead Shielding

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Purpose: The effect on surface dose from underlying lead shielding in water was investigated for therapeutic kilovoltage x-ray beams by experimental and Monte Carlo methods. **Method and Materials:** A Farmer type ionisation chamber was used to measure the surface dose in a water phantom for x-ray beams with energies from 75 to 135 kVp. A 5 mm thick lead sheet was positioned at various depths below the surface. The surface dose ratio was calculated by comparison with the surface dose with no lead sheet present. A Monte Carlo model of the x-ray beam and the phantom was generated using the EGSnrcMP code (V4.2). The initial energy spectrum was determined using an empirical method and verified by calculation of depth dose data. The dose was scored in a 1 mm thick slab at the phantom surface. The change in surface dose was calculated as a function of depth to the lead and compared to measured data. **Results:** The reduction in surface dose was a function of x-ray beam energy, beam area and the depth of water to the lead. As the depth of water to the lead sheet decreased, there was a reduction in the surface dose. With the 8 cm diameter applicator and 1 cm depth of water to the lead, the surface dose ratio was 0.918 for the 75 kVp x-ray beam and 0.890 for the 100 kVp x-ray beam. For the smaller applicators, there was less reduction in the surface dose ratios. Surface dose ratios calculated by the EGSnrcMP code were in good agreement with measured data, with a maximum deviation of 1.2%. **Conclusion:** The surface dose for kilovoltage x-ray beams is reduced when lead is underlying in the phantom. The Monte Carlo results indicate the model is sufficiently accurate to predict changes in the surface dose.

SU-FF-T-182

Analysis of Systematic Uncertainty in Vivo Dosimetry Using Diodes

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Purpose: This study analyzes systematic uncertainty of in vivo dosimetry using diodes. Several possible sources of error are investigated to eliminate or correct systematic errors. **Method and Materials:** Two diodes are placed on both sides of a phantom/patient to measure entrance and exit doses. The midline dose can thus be derived from these entrance and exit doses. We selected patients with tumors in their midline and with geometrically symmetric structures Several experiments are specially designed to measure response variation of diodes (1) due to temperature change, (2) with/without mask presence, (3) with different types of tapes used to fix the diodes, (4) with the space between mask and skin, (5) with the off field edge distance, and (6) with inhomogeneity of the patients. **Results:** The systematic uncertainty for measurement with/without the mask is 1%. The systematic uncertainty for temperature change is 3~4%. The systematic uncertainty from different types of tapes is 1% .The systematic uncertainty due to space between the mask and the skin is less than 2%. If the diodes were placed off edge for distances greater than one-fourth of the field size, the systematic uncertainty is less than 2%. **Conclusion:** Temperature change may be an important source of error for in vivo dosimetry using diodes. Other sources of error we investigated produced uncertainties less than 2 %.

SU-FF-T-183

Application of a Gantry-Mounted Diode Array System for QA Dosimetry of High-Energy Photon Beams

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Purpose: To investigate the utility of a commercial diode-array system mounted on the gantry of linear accelerators to perform relative QA dosimetry of photon beams at different gantry angles. **Method and Materials:** The diode-array Profiler (Sun Nuclear Corp.) was mounted on

the head of the linac. Beam profiles were measured at multiple gantry angles for 6 and 10 MV photon beams. Flatness, asymmetry, and central-axis relative output were determined. Dynamically-wedged (EDW) profiles were measured at various gantry positions for different wedge angles. For a given EDW field, the speed of the Y-jaw motion was varied by changing the number of MUs for studying the effect of jaw speed on the EDW profile. The potential effects of gravity and leaf speed on the dynamic delivery of MLC-based IMRT beams were also investigated. The IMRT fields were designed such that the MLC leaves move against or along gravity when the linac gantry is at horizontal position. The MLC leaf speed was varied by changing the total MU. **Results:** (1) The gantry angle has no influence on the flatness, asymmetry, and the central-axis output of the clinical beams. (2) Our data validated the delivery of EDW treatments at any gantry position. (3) For IMRT fields, the beam profiles are accurately reproduced at any gantry angle for all leaf speeds. No gravity effect on dMLC delivery was observed. However, the diode-array system was able to detect a difference of about 3% in beam profiles produced by leafs traveling in opposite directions at a high leaf speed of 2.5 cm/sec, attributable to the communication time lag between MLC controller and the Linac beam control but not to gravity. **Conclusion:** The gantry-mounted linear diode array Profiler is an efficient tool for performing QA of basic beam characteristics, EDWs, and dMLC, especially at different gantry angles.

SU-FF-T-184

Automated Dose Determination On the Midsagittal Plane Based On Skin Measurements During TBI

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Purpose: To determine the patient dose in the midsagittal plane based on a series of MOSFET measurements on the patient's skin during total body irradiation (TBI). **Method and Materials:** The patient is in the sitting position with her midsagittal plane perpendicular to the photon beam and covered with water-equivalent rice bags on the beam side during TBI. The rice bags simulate a box of water surrounding the patient. A plastic plate rests against the patient and the rice bags on the beam side (irradiated from both left and right). Eight to ten MOSFET dosimeters are placed under bolus pieces on the patient's skin on both sides of her body during each beam irradiation. Conversion of the MOSFET readings to midsagittal dose is necessary for the MU adjustments, if necessary. The reasons this is non-trivial and needs to be done quickly are, (a) the imitated box is not complete on the exit side of the beam, (b) the summation of both the entrance and exit beams need to be considered for dosimetry, (c) some irradiation sites such as the neck and legs have different thicknesses than that of the torso, and (d) MU adjustments need to be determined promptly, since a TBI patient is under tremendous stress. **Results:** The midsagittal dose can differ from the skin dose by as much as -25% to 40% depending on the irradiation, measurement, and anatomical geometry. The automated code uses the pre-measured PDD for the TBI setup. The variables are the thickness of the torso, the thickness of the anatomical site (e.g. pelvis or neck), and the distance between the dosimeter and the plastic plate. **Conclusion:** The automated code designed for TBI dosimetry is robust, accurate, fast, and displays the parallel-opposed beam geometry that is different for every patient and dosimeter placement.

SU-FF-T-185

Commissioning of a Mobetron Electron Linear Accelerator

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Purpose: The purpose of this paper is to describe the commissioning of our Mobetron electron linear accelerator and share the experience gained during the commissioning process. **Method and Materials:** The Mobetron is a relatively lightweight and mobile linear accelerator that has been developed for use in an operating room suite for delivering intra-operative radiation therapy. This accelerator is capable of delivering a therapeutic beam of electrons with nominal energies of 4, 6, 9 or 12 MeV. The Mobetron comes with a variety of circular cones, ranging in field size from 3 to 10 cm diameter, in 0.5 cm increments, and 3 different angles, flat, 15 and 30 degrees. For each energy and cone, the percent depth dose (PDD), isodose distribution and output factor were measured. These measurements were performed in a water phantom. A dose per MU calibration was performed for each energy, using the 10 cm flat cone, according to the TG-51 protocol. The stability of this output was monitored as a function of time. Finally, dose values were measured at various locations around the Mobetron during operation in order to determine shielding requirements and warm-up procedures. **Results:** PDDs and isodose distributions for the various cone sizes, cone angles and beam energies are presented. Additionally, plots of output factors as a function of field size for the 3 different sets of cones and beam energies are provided. Lastly, the doses at different locations around the Mobetron are shown and the impacts of these doses on shielding and warm-up procedures are discussed. **Conclusions:** The commissioning is complete. PDDs and isodose distributions measured for the Mobetron were similar to those measured for the linac used previously. Due to the machines' design, we found the output did vary with time, by as much as 3% over a period of about 10 days.

SU-FF-T-186

Commissioning of Tissue Inhomogeneity Correction of Eclipse Radiation Treatment Planning System Using a Lung Phantom

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Purpose: It has been noted that dosimetric difference due to tissue inhomogeneity is significant for a lung patient. If there is no tissue inhomogeneity correction (IC) made, the treatment plan could mislead treatment. Commercial radiation treatment planning (RTP) systems have the capability to include tissue IC. To utilize IC, each correction method should be reviewed and verified in advance. This study presents the commissioning of tissue IC in the Eclipse RTP system for three methods; Batho power law (Batho), Modified batho (Mo-Batho), and Equivalent TAR (E-TAR). **Method and Materials:** Treatment plans were mapped onto CT images of a lung phantom. Dose was calculated once without IC and three times with different correction methods each time. Doses were measured at three different locations, one inside of the lung in the phantom, one in the body in between lungs, and the last one in the bone. **Results:** The results demonstrate that the calculated without tissue IC could be significantly different from the measured dose in the treatment room. This difference varies depending on the extent to which each radiation field passes through inhomogeneous tissues. This study proves that the currently available correction methods reduce the error made due to tissue inhomogeneity. The calculated dose without IC was 5 – 10 % from the measured dose at the point inside of the lung or in between the lungs. The difference ranges 2 – 3 % using Batho, 1 – 3 % using Mo-Batho, and 0 – 4% using E-TAR. However, the calculated dose to the point inside of the bone was about 2 – 5 % different from the measured dose regardless of the use of IC. **Conclusion:** This study overall favors the use of inhomogeneity correction for treatment plans. Among all correction methods in Eclipse, Modified batho is recommended based on this study.

SU-FF-T-187

Comprehensive Empirical Formulation for Treatment Planning of Small Clinical Electron Fields

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Purpose: To develop a comprehensive empirical formulation to predict the dosimetric properties of small electron fields at nominal and extended SSDs. **Method and Materials:** A set of circular electron cutouts with physical diameters from 2 to 9 cm was constructed in the usual clinical manner. A full dosimetric analysis of the fields defined by each cutout was done for nominal electron energies between 6 and 20 MeV using a 3D water phantom and a pin-point ion chamber. Properties studied included depth dose, in-air inverse-square fall-off, and beam profiles. After appropriate benchmarking, these properties were further studied with Monte Carlo simulations using the BeamNRCMP code. From the physical data and simulations the following parameters were determined for each cutout/energy combination: R50, R90, widths of 90% and 95% isodose surfaces, effective SSD, and dose output factor. The parameters were then correlated with collimator size, giving a suite of equations accurately defining the dosimetric properties of these fields. **Results:** Rules of thumb regarding properties of electron fields are typically used in deciding the shape and nominal energy of electron fields. The cadre of formulas developed in this work more accurately predicts the dosimetric behavior of small electron fields where significant deviation from expected dosimetry

can occur. We found a large difference in the 95% and 90% isodose widths as a function of field size and nominal beam energy. Moreover, the effective SSD was found to be a strong function of field size. **Conclusion:** The formulation developed in this work accurately describes the clinical dosimetric properties of small electron fields. It can be used to select the size and shape of an electron cutout needed to provide the desired coverage at a given depth. Furthermore, the output of these small fields can also be calculated, obviating the need for a measurement.

SU-FF-T-188

Correlation Between in Vivo Electron Diodes Response and Nominal Surface Dose for Broad Electron Beams

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Purpose: To establish correlation between in vivo diodes response and nominal surface dose Ds for broad electron beams, thus simplifying the calibration process for electron diodes. **Method and Materials:** The nominal surface dose Ds defined by TG25 was extracted from electron PDD data that were measured by cylindrical ion chamber (RK chamber, Scanditronix-Wellhofer) on a Varian 2100C Linac at 100 cm SSD. Cone factors were measured using ion chamber (Capintec PR-06) at d_{max} .
A QED p-type electron diode with Model 1131 dosimeter (Sun Nuclear Corp.) was calibrated to the dose at d_{max} for 9 MeV electron beam at 100 cm SSD using 10×10 cone. Diode readings using this calibration factor were then obtained with 10×10 cone and 15×15 cone for 6, 9, 12, 16 and 20 MeV electron beams delivering 200 MUs.
The same diode was then re-calibrated to the dose at d_{max} for 12 MeV electron beam. The above measurements were repeated with 10×10 cone and 25×25 cone to reconfirm our hypothesis. **Results:** The diode readings were first divided by cone factors, and then the corrected readings were plotted against nominal skin dose. For diodes calibrated by 9 MeV electrons, the correlation coefficient R-squared value were 0.9954 and 0.9796 for 10x10 cone and 15x15 cone respectively. For diodes calibrated by 12 MeV electrons, the R-squared value were 0.9967 and 0.9980 for 10x10 cone and 25x25 cone respectively. **Conclusion:** The correlation between in vivo p-type diode response and nominal surface dose Ds for broad electron beams has been empirically established and confirmed. The diode response corrected by cone factor demonstrated a clear correlation with nominal surface dose Ds. This correlation can significantly simplify the electron diode calibration process. It can also be potentially used to monitor relative skin dose along with d_{max} dose at the same time.

SU-FF-T-189

Custom-Made Ion Chamber for Daily QA in RT

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Purpose: A computerized dosimetric system with air-tight ion chambers and on-board electrometer has been devised to measure daily output checks of 4/6/10/15 MV X-ray of linear accelerators. It can be inserted into the blocking tray or can be setup on the treatment table of the linear accelerators. **Method and Materials:** The dosimetric systems consists of three parts : (1) air-tight plane-parallel ionization chamber, (2) on-board electrometer, (3) computer interface. The ionization chambers (10mm diameter * 2mm width) are implemented on printed circuit boards (PCB) with acrylic plates. Three electrodes are fabricated using approximately 100um thick gold/lead/cupper coating on the PCB board. The buildup plates ranging from 1cm to 3cm depending upon x-ray or electrons. The electrometer is designed using a typical current-to-voltage converter (ACF2101, Burbrown, USA) with 20-bit ADC circuits (ADC1210, Burbrown, USA) , (3) The ADC output is transmitted via RS-232 interface to a personal computer. The power from rechargeable battery is supplied all the time to the electrometer, thus eliminating warm-up time. **Results:** The short and long term stabilities of the ion chamber are found to be less than 0.2% (one standard deviation) with reference of standard dosimetric system. Also, it is extended to be a 9-channel dosimetric system as a QA device of implementing transit dosimetry (+/-3% agreements between expected and measured values) to determine the overall performances of radiation therapy for the head/neck and breast treatments. **Conclusion:** The daily QA devices of measuring the output of linear accelerators (6EX and 21EX of Varian linear accelerators) are proven to be very effective. It will be modified to measure the output and the PDD (in a step of 1cm) of the electron beams as a weekly QA.

SU-FF-T-190

Daily Quality Assurance (QA) Procedure of On-Board Imager (OBI)

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Purpose: Developed a daily QA procedure for checking; 1) the accuracy of the imager isocenter and 2) the auto couch motion accuracy of the On-Board Imager (OBI) device developed by Varian. This QA procedure will assure that the imager isocenter matches the mechanical isocenter and that the positional difference detected by the imager software can be reliably transferred to couch motion. **Method and Materials:** The Cube Isocenter Phantom provided by Varian was used for this daily QA procedure. Two sets of bb were used to define 2 separate spatial locations (points.) In each set, one bb is on the anterior side (AP bb) and the other (Lat bb) is on the lateral side of the phantom. The first set defines the isocenter (at the phantom center) and the second set defines a point 1.5 cm anterior, inferior, and lateral from the isocenter. An axial CT scan was acquired with a slice thickness of 2 mm. A plan with an AP MV and a Lat KV fields was created in Eclipse with the corresponding DRRs attached. The QA procedure starts with setting up the phantom center at the mechanical isocenter and taking AP MV and Lat KV images. The locations of the central bbs were first checked to get the accuracy of the imager isocenter. If that accuracy is acceptable, the central bbs in the KV/MV images were then manually moved to overlay to the off-axis bbs in the DRR images. The shifts obtained will be applied to remotely move the couch. All data will be recorded. **Results:** This OBI QA procedure is simple and easy to implement. It usually takes 10-15 min to do the QA. The_accuracy the procedure can detect is better than 2mm. **Conclusion:** The suggested QA procedure is clinically robust and reliable

SU-FF-T-191

Design and Construction of a Realistic Pelvic Phantom for a Level III Dosimetry Study

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Purpose: Verification of dose delivery is a basic necessity of quality assurance in radiotherapy treatment, and is extremely valuable in determining uniformity of protocol adherence in the context of a multi-centre trial. To verify the delivery of radiotherapy doses and dose distributions it is necessary to replicate the entire treatment process as accurately as possible in a way that allows the direct measurement of doses. A pelvic phantom was constructed to investigate the 3D delivery of radiotherapy (Level III dosimetry) for rectal and prostate cancer treatment in collaboration with the Trans-Tasman Radiation Oncology Group. **Method and Materials:** A CT dataset of a male pelvis was used to define the geometric boundaries of principle tissues – bone, prostate, seminal vesicles, bladder, rectum and muscle. Points of interest were located throughout the dataset to identify appropriate placement of TLD materials. The centre of the prostate was identified as the location for point-measurement with a small-volume ionization chamber. Polyurethane materials for phantom construction were evaluated in terms of their durability, ability to be milled and radiographic qualities. **Results:** The pelvic phantom has been manufactured and has undergone commissioning. CT numbers for different density materials match well with typical tissues. TLD measurements in the phantom show a reproducibility of 2 %. The proposal for the inter-centre study has led to a high (> 85 %) accrual of radiotherapy centres in Australasia. The phantom has now been used at a large number of participating centres. **Conclusion:** This study will provide estimates of variation in critical structure outlining, expansion algorithms and dose volume histograms across different planning systems. In addition local irradiation techniques, geometric and dosimetric accuracy dose distributions in realistic materials, and the feasibility of multi-centre dosimetry studies is assessed.

SU-FF-T-192

Determination of Skin Dose for Hypo-Fractionated Breast Treatment Using Mixed Photon and Electron Beams

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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 at the skin surface and at a depth of 0.07 mm, the practical reference depth for skin as recommended by ICRP and ICRU, using ultra thin TLDs and Monte Carlo calculations. **Method and Materials:** Monte Carlo simulations and measurements were carried out for 5x5 cm^2 and 10x10cm^2 fields for 6, 10 and 18 MV photon beams as well as for electron beams of energies ranging from 6 to 21 MeV. For photon beams, the variation of the surface dose with angle of incidence and field size was investigated. Also, the exit dose was computed and measured for the same fields and angles of incidence. The dose at the ICRU reference depth was also computed for the electron beams at normal incident angles. Finally, the dose was measured and calculated for breast IMRT plans followed by dose uniformity enhancement by an additional electron beam for conventional and hypo-fractionated treatment protocols. **Results:** Good agreement (±5%) was achieved between measurements and calculations. The surface dose at the entrance was increased as the angle of incidence and/or the field size increased. The exit dose was decreased as the angle of incidence increased but increased with field size. **Conclusion:** The dose at the surface of the patient is mostly dependent on the beam energy, modality and beam obliquity rather than the field size and field separation. 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-193

Dosimetric Responses at Different Gantry and Collimator Angles in Dynamic MLC Beam Delivery

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Purpose: IMRT uses Dynamic Multi-Leaf Collimator (DMLC). This study is to investigate the DMLC performance at different gantry and collimator angles based on dosimetric measurements. Conformity index and symmetry index were introduced to quantify the performance. **Method and Materials:** We developed a technique to measure the dosimetric impact of DMLC delivery at different gantry and collimator angles. Various DMLC patterns were designed to observe the discrepancies of the DMLC delivery at different gantry collimator angles. The discrepancies were quantified by acquiring dosimetric information under the corresponding radiation delivery conditions. The designed dynamic fields were delivered using 6 MV photon beams to a Solid Water™ phantom with an ion chamber at the isocenter. Phantom was carefully set up so that both the phantom and the chamber remained the same, geometrically,with respect to the beam's coordinates when the gantry angle was changed. The measurements were carried out for two Varian's 23Ex Liancs. Conformity index was defined to measure the output ratios at different gantry angles for a same DMLC pattern. Symmetry index was defined to assess the dosimetric discrepancies of the same pattern with opposite collimator setting at a same gantry angle. **Results:** The same measurements were performed for each machine for five consecutive days. It was observed that conformity index varied within between 98% and 100%. And the results varied on daily basis, which may imply the slight instability of DMLC performance. A consistent value less than 100% for the conformity index may indicate a gravity effect on the DMLC performance. In the meantime at a fixed gantry angle and at different collimator angle with a same DMCL pattern, the symmetry index varied randomly from 97.5% to 102.2%. **Conclusion:** The gravity may affect the DMLC dosimetric performance. This impact on IMRT dynamic delivery warrants further investigation.

SU-FF-T-194

Evaluation of a Commercial Diode Array (Tomodose) for Tomotherapy Beam Profile Measurements

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Purpose: TomoDose, a commercial diode array (Sun Nuclear Corporation, Melbourne, FL) is used to measure the radiation field in a TomoTherapy Hi* Art linear accelerator. The performance of TomoDose is evaluated by comparing the diode measurements with (i) ion chamber based water tank measurements and (ii) data from an on-board ion chamber array mounted opposite the linac. **Method and Materials:** TomoDose has an active area that is rectangular (530 mm by 96 mm) to cover to the maximum field size (50 mm by 400 mm) of the tomotherapy beam. A total of 223 diodes allow a measure of the lateral and longitudinal beam profiles on the central axis and longitudinal profiles 50, 100, and 150 mm off-axis. Both central axis profiles were compared with ion chamber data obtained in a water tank during an annual quality assurance test. Over a period of about seven weeks, the central axis lateral profile was monitored and compared with profile measurements obtained using the treatment machine's on-board detector system. **Results:** TomoDose measurements agreed well with the ion chamber data. A repeated measurement of the lateral profile revealed subtle changes in this profile. Identical trends in profile change were independently measured using an on-board detector array system. These changes were used for diagnosis of the system's components and can be used to provide early signs of component wear and tear. **Conclusion:** TomoDose is accurate and can be used for regular, e.g. monthly, monitoring of the beam profiles. It is sensitive to subtle changes in the profile that may be used to provide early warning signs of developing problems. **Conflict of Interest:** Two of the co-authors are employees of TomoTherapy, Inc..

SU-FF-T-195

Evaluation of Film Calibration Procedures for Quality Assurance of Helical Tomotherapy Treatments

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Purpose: To evaluate and compare film calibration procedures using a conventional 6 MV static beam and an optimized helical tomotherapy plan for the patient-specific QA of tomotherapy treatments. **Method and Materials:** The conventional 6 MV static beam was delivered by a Varian 2300CD Clinac to blocks of solid water. Three different doses were delivered to each of two Kodak EDR2 films, giving a total of six dose values. Cerrobend blocks were used to cover portions of the film outside each field in order to prevent contamination from one field to the others. The optimized helical tomotherapy plan was delivered by a TomoTherapy Hi-Art™ System to a cylindrical solid water phantom. Nine cylindrical ROIs were contoured within the phantom along the horizontal and vertical axes. This procedure produces two films with a total of nine different dose values. All films were analyzed using in house software coded in LabVIEW™. Each calibration procedure was evaluated on the basis of accuracy, efficiency and ease of implementation. **Results:** Both the conventional 6 MV static beam and optimized helical tomotherapy plan were able to deliver the dose accurately, with the static beam producing a steeper gradient in the vertical direction but better uniformity in the coronal plane. It took approximately the same amount of time to complete each procedure. **Conclusion:** The conventional 6 MV static beam is able to deliver a slightly more uniform dose to the film plane. However, the optimized helical tomotherapy plan provides sufficient accuracy, is able to add more points to the calibration curve in the same amount of time and is delivered with the same beam and phantom used to deliver the patient treatments. For this reason, the optimized helical tomotherapy plan has been implemented as the film calibration procedure for patient-specific QA of tomotherapy treatments.

SU-FF-T-196

Evaluation of the Dose Within the Abutment Region Between Tangential and Supraclavicular Fields for Various Breast Irradiation Techniques

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Purpose: To compare the uniformity of dose in the abutment region (matchline) between breast tangential and supraclavicular fields produced by irradiation techniques having different means of forming the match (e.g. external block, MLC, collimator jaw). **Method and Materials:** A film dosimetry system was developed and validated by comparing lateral and percent-depth-dose (PDD) profiles measured with EDR2 film in a plastic water phantom to ion chamber measurements made in water. Field sizes of 5x5, 10x10, and 20x20 cm^2 were examined covering a range of depths. Once established, EDR2 film was placed in solid phantom at various depths and used for characterization of the abutment region produced by several three-field intact-breast irradiations. The abutment regions (+/- 2.5 mm on either side of the central matchline) of the various techniques were analyzed via a Dose Area Histogram (DAH) and compared to each other. Preliminary data are presented, in which DAHs are used to evaluate the abutment region between a field collimated with a jaw and another field collimated with the configurations mentioned above. **Results:** **C**haracterization of the film dosimetry system demonstrates that, for all field sizes and depths, all lateral profiles and depth-dose curves measured agree with ion chamber measurements to within < 3% in low dose gradient regions and < 2 mm distance to agreement (DTA) in high dose gradient regions (≥ 30% cm^{-1}). Inspection of preliminary abutment region data indicates that the DAH clearly and sensitively demonstrates uniformity differences between the various methods used to create the match. **Conclusion:** We have developed a film-based dosimetry tool that uses DAHs to accurately portray relative dose distributions within the abutment regions of smooth-edge and MLC-produced fields. This tool will be used, subsequently, in an anthropomorphic phantom using actual breast treatment fields. **Conflict of Interest:** Research supported in part by Varian Medical Systems.

SU-FF-T-197

Filmless Radiation Isocentre Localisation Using An Electronic Portal Imaging Device

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Purpose: The increased availability of electronic portal imaging devices (EPID) on linear accelerators provides a capability to replace film with enhance standard commissioning and validation measurements. A series of EPID based measurements have been developed to confirm the coincidence of the radiation and mechanical isocentre with gantry, collimator and table rotation, eliminating the need for traditional star-shots films and enhancing the information gathered from such tests. **Method and Materials:** A precision phantom containing a set of radio-opaque markers was positioned at the mechanical isocentre using a calibrated front pointer. The EPID was positioned at an SID of 140 cm, and a series of images for a 4×10 cm^2 where acquired in IMRT mode for different angular rotations of gantry, collimator and treatment table. Images were exported to a MatLab based program which automatically identified the position of the radio-opaque markers and field edges to determine the relative motion of the isocentre with angle. **Results:** Measurements were performed with several different models of aSi imager found on Varian and Elekta Precise treatment units, and compared to the results of traditional star shot films. The measurements were consistent, with the radiation isocentre confined to a 2 mm diameter sphere. In addition, the EPID based tests provided additional information on the longitudinal motion of isocentre typically not available from film star shots. **Conclusion:** EPID based measurements can replace the use of film in geometric verification tests typically performed during commissioning and annual quality assurance. These measurements are at the same time simpler to perform and analyze, while increasing the information extracted from the measurements and providing a reliable, user independent method of monitoring changes to the treatment unit isocentre over the lifetime of the machine.

SU-FF-T-198

Head-Scatter Off-Axis for MLC Shaped Fields

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Purpose: Off-axis head-scatter is the major contributor to doses outside x-ray collimation. For an IMRT beam, these scattered photons also affect the dose inside the treatment field. This study determines the headscatter components for an accelerator with MLC as an attachment. **Method and Materials:** Head-scatter is measured for the 6 and 18 MV photon beams from a Varian 2100C linear accelerator. The head scatter off-axis, *HOA*, is defined as the scatter-to-primary ratio for head-scatter with collimator setting *cx* □ *cy* at off-axis position *x*, i.e., *HOA(cx,cy,x) = (T(cx,cy,x) - P(cx,x))/P(cx,0),* where *T* is the total dose measured in a graphite miniphantom for collimator setting *cx* □ *cy* at position *x* and *P* is the primary dose measured at the same location *x* under a collimator setting of *3* □ *cx*. The collimator setting along *x, cx,* is kept the same so that the primary remains unchanged. The results are fitted to a two-source model [1]. **Results:** The widths of the two Gaussian sources are 1.4 and 16 cm, respectively, for both energies. Compared to the leakage outside beam collimation, *HOA* at 2 cm outside field width is 100 % of the primary for c = 5 cm to 400 % of the primary for c = 30 cm. **Conclusion:** Compared with the conventional collimator jaws, HOA for MLC shaped field is lower at off-axis locations due to the difference in physical locations of the MLC and the collimator jaws. 1.Zhu TC and Bjarngard BE, "Head scatter off-axis for megavoltage x rays," Med Phys 30: 533 – 543 (2003).

SU-FF-T-199

Heterogeneity Effects in Small-Field Macular Irradiation

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Purpose: To evaluate the effects of bone heterogeneities on the dose distribution to the macula in small-field macular irradiation. **Method and Materials:** An elliptical aperture measuring 8 mm x 10 mm on the major axes was constructed to project a circular field onto the macula through each of six fields focused on the macula and angled 28 degrees relative to the central axis of the eye. Using a stereotactic diode, the Tissue-Maximum-Ratio was measured for this aperture to a depth beyond the macula. These measurements were repeated using bone-density material in order to approximate the attenuation through the cartilage of the nose and the supra-orbital ridge. The beam profile at the depth of the macula was determined by film densitometry and the profiles for strictly soft tissue overlay were compared with the profiles for given thicknesses of bone density phantom added to the soft tissue. Lastly, the profile was determined for bone-density phantom covering only half the field to simulate a treatment situation where the supra-orbital ridge might intersect only half the incident field. **Results:** The excess attenuation of the bone material representing cartilage or supra-orbital ridge is easily described by a simple exponential. The beam profile at the depth of the macula appears unchanged from the beam profile for soft tissue overlay, while the beam profile as modified by bone density material covering half the field shows a measurable attenuation through the bone. However, there is no widening of the profile in any of these situations. **Conclusion:** These results suggest that a small-field pencil beam photon algorithm should be sufficient to calculate the radiation dose distribution for macular irradiation. Pencil beam and Monte Carlo dose calculation algorithms will be compared against these measurements. **Conflict of Interest:** This work supported by an SBIR grant to DIACOR, Inc.

SU-FF-T-200

Image-Guided IMRT Dose Verification with a Plastic Photosensitive Dosimeter

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Purpose: To verify an IMRT treatment, multiple point dose measurements are time-consuming to acquire. This investigation used a kilovoltage imaging system to localize an optical dosimeter to acquire rapidly three-dimensional IMRT quality control measurements. **Method and Materials:** A plastic photosensitive dosimeter was used as a dosimetric verification tool for IMRT. The plastic was formed into a right cylinder 8cm in height and 9cm in diameter that fit precisely into a water equivalent phantom. The

system was used to verify an IMRT dose distribution computed by inverse treatment planning and delivered using a medical linear accelerator equipped with a multi-leaf collimator and a kilovoltage electronic portal imaging device (KV-EPID). The KV-EPID was used to determine the location of the dosimeter cylinder within the accelerator coordinate system. Small wires (1mm diameter) inserted into the cylinder at three locations were used as fiducial markers. An auto-matching algorithm integral to the accelerator control system was used to assure that the position of the dosimeter matched the position in a phantom plan. The Root-Mean-Square localization error was measured to be 1.1mm. The dose distribution within the dosimeter was measured by means of an optical cone-beam imaging system. The measured dose distribution was compared with the calculated dose distribution based on the known locations of the fiducial markers. **Results:** The KV-EPID was easily able to visualize the fiducials in the dosimeter and to localize the dosimeter with a RMS error of 1.1mm. **Conclusion:** The dose distribution delivered by IMRT to a surrogate phantom can be aligned with a mean error of 1mm using the KV-EPID. This allows optical reconstruction of a photosensitive plastic dosimeter to be aligned with the computed three-dimensional dose distribution for dosimetric verification of an IMRT treatment plan.

SU-FF-T-201

Implementation Of EPID Based Quality Assurance Procedures For Radiation And Optical Fields

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Purpose: Enhanced radiation and light field quality assurance (QA) procedures have been developed and implemented utilizing amorphous silicon electronic portal imaging devices (EPID). This effort was motivated by the fact that film exposure coupled with hand measurements are extremely time consuming and prone to many sources of error. **Method and Materials:** The EPID based QA procedure uses specially designed acrylic test templates, containing radio-opaque led bars to register the position of the optical field. Images of these templates were acquired with the EPID on both Varian and Elekta linear accelerators. A MATLab based computer application was used to automatically assess light/radiation field congruence, radiation field sizes and optical field size and positioning. A three-month pilot study using two Varian accelerators to assess both 6 MV and 18 MV photon energies was performed to validate the EPID QA procedure's efficacy and quantify its efficiency relative to film QA procedures. **Results:** The pilot study verified that the EPID QA system results are congruent with the hand measurements obtained from a detailed analysis of film QA measurements. Light/radiation congruence measurement performed using an EPID exhibited an absolute mean deviation of 0.37 ± 0.37 mm (1σ), relative to the film measurements. EPID based radiation field size assessments produced an absolute discrepancy of 0.57 ± 0.44mm (1σ), while film measurements yielded an absolute discrepancy of 0.61 ± 0.55mm (1σ), relative to measurements acquired using RIT software. EPID based measurements were found to be more efficiently performed, reducing the set-up and analysis time by 55% compared to film. **Conclusions:** The enhanced EPID QA system can effectively replace film in routine quality assurance tasks for radiation and optical fields. This procedure saves Princess Margaret Hospital 4 man-hours per week, and provides a user-independent analysis procedure for objectively assessing routine QA results.

SU-FF-T-202

In Vivo Dosimetry Using Diodes Detector for External Photon Treatments of Head and Neck Cancers

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Purpose: In vivo dosimetry is a tool to ensure the accuracy of delivery of the radiation treatments. By in vivo dosimetry, the incidence of errors could be monitored. Based on experiment results, we want to establish an in vivo dosimetry standard protocol. **Method and Materials:** Measurements of entrance and exit doses were performed with diodes on patients' surface. After obtained entrance and exit doses, we used transmission curve to derive midline dose. Before entrance and exit dose measurements, we need to measure the calibration factor for diode reading to dose and, correction factors for nonstandard SSDs and field sizes. Measurements were made for 6MV photon fields (Varian 2100C/D machine). The detectors were VeriDose 30-472 (5-11MV) diodes. The midline dose was calculated by our hand calculation system without inhomogeneous correction. **Results:** The total field number for patient measurements was 204. Before measuring in vivo doses, we delivered these fields to a plastic water phantom. Comparisons between phantom results and midline doses measured by the ionization chamber show the mean relative discrepancy was 0.184% with 0.5% corresponding SD. The mean relative discrepancy between midline doses measured by diodes and planning target doses from prescription for patient measurements was -1.08% and SD was 3.09%. If we averaged two opposed beams dose, the standard deviation of reletive error will be 2.35%. Further, we corrected our estimated dose by inhomogeneous correction depth which was averaged by two opposed beams measurements, the mean and standerd deviation we obtain was -0.16%(1.39%). **Conclusion:** After phantom and patient studies, we conclude that in vivo dosimetry is a practical way to inspect dose accuracy.

SU-FF-T-203

In Vivo Dosimetry Using Disposable MOSFET Dosimeters for Total Body Irradiation

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Purpose: The "OneDose" MOSFET dosimeter, manufactured by Sicel Technologies, is used for individualized patient dosimetry measurements for radiation therapy. These dosimeters, which are pre-calibrated by the manufacturer, are designed for single use for conventional radiation therapy treatments. We tested the usefulness, reliability and applicability of these dosimeters for use in total body irradiation procedures, where the field sizes, distances, and irradiation conditions differ substantially from the standard conditions used for factory calibration **Method and Materials:** We have compared the response of OneDose dosimeters with that of Thermoluminescent Dosimeters (TLDs) calibrated 'in-house'. OneDose dosimeters were paired with two TLDs and were placed beneath bolus to provide adequate build-up. The detectors with build-up were then taped to the skin of the patient at various sites of interest, including the head, neck, umbilicus and lungs. In most cases, cerrobend lung blocks were used. Readings of the OneDose were taken immediately following irradiation. The TLDs were read 2 – 4 days later. **Results:** Of the four patients studied thus far, the doses measured at the head, neck, and umbilicus fell between 105 and 210 cGy. For these sites agreement with the TLDs was generally within ±5%. Measured doses for the regions of the lung showed greater variability. This may be due to placement errors or the lower doses (< 20 cGy) and steeper dose gradients that occurred when the lungs were shielded with cerrobend blocks. **Conclusion:** The dose measured by the OneDose detector shows relatively good agreement with that measured by TLDs in total body irradiation. Our research plan includes study of another six patients, with the intent of being more precise in the placement of the dosimeters in the region of the lung. **Conflict of Interest Information:** ASB has a sponsored research agreement with Sicel Technologies, Inc. for the study of implantable sensors.

SU-FF-T-204

In Vivo Force-Torque Measurement During Prostate Brachytherapy

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Purpose: The main goal of this study is to measure the needle insertion force/torque (F/T), velocity/ acceleration (V/A), and tissue/organ deformation during actual brachytherapy procedures in the operating room (OR). These *in vivo* data will guide the design of a Robot-Assisted Platform for Intratumoral Delivery (RAPID) system. **Method and Materials:** We have acquired F/T and V/A data from actual patients and a single surgeon placing brachytherapy needles in the OR using a hand-held adapter equipped with a 6 degree-of-freedom (DOF) F/T sensor (Nano25^{TM}). During this *in vivo* measurement, the needle progression into the soft tissue was registered using ultrasound (US) imaging technique. A 6 DOF electromagnetic (EM)-based position sensor (miniBIRD$^{®}$) was attached to the hand-held adapter to measure 3D position and orientation of the hand-

held adapter. **Results:** The *in vivo* data reveals that maximum needle insertion force is about 18N, velocity is about 72cm/s, and acceleration is about 3000cm/s^2. This relatively high acceleration may have some implications on the inertia force, which may help the surgeon in needle insertion. We observed significant transverse force (about 1.7N). From *in vitro* data it was observed that the force and torque during robotic needle insertion in animal soft tissues were significantly smaller as compared to that for humans. **Conclusion:** Additional *in vivo* data are being collected from different patients to study the effects of patient specific criteria such as age, height, ethnicity, body mass index (BMI), prostate specific agent (PSA) value, special anatomy, previous treatment, etc. on needle insertion force/torque and tissue deformation. Since frequent *in vivo* data collection and experimentation are impractical, we will use these data to determine the soft animal tissues and soft materials which have close resemblance to human tissues.

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SU-FF-T-205

Ionization to Dose for Electron Beams: A Comparison of Three Approaches

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Purpose: To compare methods of converting depth-ionization to depth-dose for electron beams. The current TG-25 standard is based on TG-21 calibration protocols and uses stopping power ratios for monoenergetic beams. The current IPEMB code of practice uses stopping power ratios for realistic electron beams, which are also used for the current TG-51 and other electron dose calibration protocols. **Method and Materials:** Depth-ionization curves measured with a cylindrical ion chamber were converted to percentage depth dose (pdd) using the current TG-25 approach, the current IPEMB code of practice, and a hybrid method that uses the stopping power ratios of the latter and the replacement correction of the former. For depths greater than the practical range, the stopping power ratio and the replacement correction were set to the values at the end of the practical range. **Results:** For energies of 12 MeV or lower, and depths greater than d_{max}, all method give results that are almost identical. In the buildup region, the hybrid pdd was up to 0.8% higher than the TG-25 approach and up to 1.0% less than the IPEMB code of practice. For 16 MeV in the buildup region, the hybrid pdd was almost identical to the TG-25 pdd but 0.7% lower than the IPEMB pdd. For 16 MeV at R_{90}, the hybrid method was about 0.6% less than TG-25 and 0.7% greater than IPEMB. For the 20-MeV beam at R_{90}, the hybrid and TG-25 results were about 1% higher than the IPEMB results. **Conclusion:** The hybrid method proposed here gives very similar results to the previous TG-25 method and the IPEMB code of practice. The IPEMB method has replacement corrections for only one size of ion chamber, so the hybrid method is more widely applicable, and should be considered as an alternative or replacement for the TG-25 method.

SU-FF-T-206

Laser Rangefinder for Automatic SSD Measurement and Inter-Fraction Patient Movement Monitoring

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Purpose: Source to Skin Surface Distance (SSD) is one of the most frequently used reference parameters for patient setup to verify the depth of treatment for external beam treatments in clinical radiotherapy. Modern machines use an Optical Distance Indicator (ODI) mounted inside the linear accelerator or a Front Pointer (FP) where the use of the ODI is precluded. In IMRT and IGRT, more precise tools are needed to monitor and record SSD, and provide information on patient movements during therapy. Additionally, automatic capture and recording of SSD data is preferential in busy clinical settings. We describe the use of a commercially available laser rangefinder to report SSD and inter-fraction patient movement in real-time. **Method and Materials:** The Acuity Research Model AR4000-LV was evaluated as a tool to measure SSD and inter-fraction movement. The device emits a visible laser spot (670 nm), and a time-of-flight measurement is obtained from the reflected beam from diffuse reflectance surfaces. Output data is provided either as a voltage or as a digital stream. The device was tested both on an optical bench (for absolute measurements) and on a phantom on the treatment couch. Tests were performed statically and during measured oscillations of the phantom. **Results:** Un-calibrated accuracy was as described by the manufacturer; ± 3.8 mm. However, precision was much better at ± 0.254 mm. Calibrated measurements improved accuracy to ± 1mm. Measurements on non-planar and tilted surfaces were also tested, and were unchanged at angles up to 45°. **Conclusion:** We show the ability of off-the-shelf technology to improve the efficiency and repeatability of SSD measurements. Also, minor patient movement can be monitored in real-time. We find the laser rangefinder to be precise, time efficient and very accurate for determining and verifying SSD. We will evaluate its use in clinical studies.

SU-FF-T-207

Linac QA Using a Computed Radiography System

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Purpose: The computed radiography (CR) is replacing film for linac quality assurance (QA) checks in our clinic. A few tools and methods were developed to facilitate this transition. **Method, Materials and Results:** A right-triangular prism phantom was used for electron beam quality verification. The phantom was centered along the beam axis, and placed on top of a CR cassette with 110 cm source to image distance (SID). The image was processed to obtain a percentage exposure vs. wedge thickness curve, which was sensitive to electron energy changes. This method demonstrated good reproducibility.

A method using a diamond-shaped template for the light and radiation field congruence test had been previously developed. This method was analyzed and modified. In the modified version, the template was put right above the CR cassette to reduce the systematic error due to the penumbra effect. An IDL program was developed to compute the discrepancies between the light field and the radiation field.

The jaw alignment was checked with a device similar to that of Lutz et al: a CR cassette sandwiched between two pairs of L-shaped Cerrobend blocks. Each pair was embedded diagonally in a piece of foam. The pair above the cassette was at an angle of 90 degrees to the pair beneath the cassette. The radiation was delivered at collimator angles of 0 and 90 degrees to verify the x-jaw and y-jaw alignment, respectively. For each collimator angle, two gantry rotations - 0 and 180 degrees - were used, with equal monitor units delivered at an SID of 100 cm.

The radiation field flatness, symmetry and penumbra were tested using CR combined with the RIT software solution. The results were consistent with those collected using films. **Conclusion:** QA checks using CR systems are more convenient and yield results comparable to those from film.

SU-FF-T-208

Modeling the Headscatter Off-Axis in Megavoltage Photon Beams

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Purpose: To accurately model off-axis headscatter from a linear accelerator at off-axis positions using a parameterized, two-component model. An improved model is now proposed to model headscatter outside beam collimation. **Method and Materials:** We define the head-scatter off-axis ratio, HOA, as the ratio of the kerma due to head-scatter photons at the off-axis position x to the kerma from direct primary photons on the central axis. “Direct primary” are those photons that come from the source without interactions in the intervening structures. We measured HOA along the X jaw direction from the central axis to a distance of 25 cm from the field edge for various collimator settings. We fit the measured HOA using an improved two-component model. The first component is a Gaussian source projected on a plane below the x-ray source, representing the headscatter from the flattening filter and the primary collimator. Compared to an earlier model [1], this model models the second component for photons scattered in the secondary (variable) collimators using a linear edge kernel integrated over the four collimator jaws. Headscatter off-axis outside beam collimation is examined more extensively with this study. **Results:** The two-component model can be fit to data obtained from a variety of fields with a mean (maximum) local relative error of 10% (35)%. The region outside the penumbra region is modeled primarily by the collimator component. **Conclusion:** A two-component model in which the headscatter from the flattening filter and the collimators are modeled separately can accurately predict HOA values for arbitrary collimator settings. [1] Zhu, T.C. and Bjärngard, B.E., Med. Phys. **30** 533-543, 2003

SU-FF-T-209

New Polymer Gel Dosimeter with High Refractive Index for Artifact-Free Optical CT Scanning

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Purpose: In order to enable optical CT scanning of gels with inserts representing tissue heterogeneities such as bone or air spaces as well as brachytherapy catheters and applicators, as well as to remove artifacts which arise when scanning across regions adjacent to container walls, we have explored the feasibility of developing a new polymer gel that would result in matching the refractive index of the gel to that of the container material. **Method and Material:** We have developed a new type of polymer gel dosimeter (and named it BANG4), based on cellulose acetate (gelling agent) in benzyl alcohol. The monomer we used in this study was methacrylic acid, which precipitates in benzyl alcohol upon polymerization. The gel is made under nitrogen atmosphere. These gels are optically clear and mechanically strong. Benzyl alcohol has the refractive index of 1.538 and methacrylic acid 1.429. Therefore, we can adjust the refractive index of the gel to match the material of the container (phantom) or insert, be it Lucite, PVC, PETG, Barex or glass. We have tested the dose response of the new gel using Torrex 150D X ray machine (EG&G, Long Beach, CA) and a spectrophotometer. We also scanned irradiated BANG4 gels in Barex and Lucite containers, using commercial OCTOPUS™ optical CT scanner (MGS Research, Madison, CT). **Results:** We found the dose response of the new gel to be linear up to 6 Gy. The optical CT images of BANG4 gels reveal that the refractive artifact was entirely removed, as can be seen from image profiles. **Conclusion:** We have successfully demonstrated the feasibility of a new class of polymer gels that can be OCT-scanned without the refractive artifact. Further studies are planned to investigate radiological properties of the new dosimeter.

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SU-FF-T-210

Performance Evaluation and Quality Assurance of Enhanced Dynamic Wedges

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Purpose: Enhanced dynamic wedges have been used in clinical practice for many years. Obvious superiority of dynamic over physical wedges is accompanied by the increased overhead involved in verifying the accuracy and reliability of their use. Contrary to very limited quality assurance (QA) required to ensure proper functioning of the physical wedges, dynamic wedges, like any other dynamic treatment, require a robust quality assurance program. This work expands upon previous suggestions and describes a comprehensive QA program for Varian Enhanced Dynamic Wedges (EDW) and presents the results of a sixteen-month evaluation of these wedges. **Method and Materials:** Daily, monthly, and annual QA procedures were devised for enhanced dynamic wedges on a dual energy Varian 21ex linear accelerator with seven wedge angles. These include daily constancy checks of the wedge performance as part of the morning QA procedure, monthly evaluation of wedge factors and profiles, and an analysis of dynamic log files generated by linac. Yearly performance evaluation includes measurement of a larger sample of wedge angles and profiles. In addition, individual treatment verification or "per patient" QA consists of visual inspection of the wedge direction at the conclusion of each treatment. **Results:** The daily constancy checks show a stable delivery of the wedged field with a variation of less than 1%. The monthly wedge factors measured have been within 1.5 % of the commissioning values. A comparison of beam profiles over the same time period shows a stable delivery of the wedged beams and good agreement with the expected segmented treatment tables (STT). **Conclusion:** An expended comprehensive QA of enhanced dynamic wedges is presented. Results of a sixteen-month evaluation demonstrate stable and accurate delivery of these fields. Due to the dynamic nature of enhanced dynamic wedge deliveries, a comprehensive QA program is necessary to verify proper delivery of these fields.

SU-FF-T-211

Pixel-Based Dead Time Correction for AS500 EPID IMRT Dosimetry

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Purpose: Recently, aS500 EPID has been increasingly used for IMRT dose verification. However, due to its system design, aS500 EPID has a dead time problem when acquiring accumulated dose, which will yield an error close to 4%. The main purpose of this study is to develop a pixel based dead time correction method for aS500 EPID. **Method and Materials:** The correction is achieved by a Matlab program which first decodes a MLC DVA file to provide leaf sequence information; and then corrects the accumulated pixel value for individual pixel based on the correlation between the leaf sequence and the time of dead time occurrence. By geometrically matching leaf-end location and individual pixel position when dead time occurs, we can identify the impacted pixels and estimate the relative percentage of the 'missing' data. Measurements of film dosimetry, EPID dosimetry with and without dead time correction are used to evaluate its effect for IMRT fields. **Results:** Applying this dead time correction, better agreement between EPID dosimetry and film dosimetry is obtained. However, the effect of dead time correction is different case by case, depends on the delivery time, MLC leaf sequence, and the total EPID signal of the IMRT field. In this study, the max correction is up to 4%. **Conclusion:** Missing dose signal caused by dead time can be successfully corrected by pixel-base dead time correction method.

SU-FF-T-212

Quality Assurance (QA) Procedure of On-Board Imager (OBI) for Portal Imaging

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Purpose: On-board imager (OBI) has been implemented to improve the in-room patient positioning. It is therefore important to establish quality assurance (QA) procedure to ensure proper functionality and operational accuracy. This report presents monthly OBI QA procedure, which includes checking collision interlocks, isocenter, digital measurements, and image qualities. **Method and Materials:** OBI system consists of mega-voltage detector (MVD), kilo-voltage x-ray source (KVS) and detector (KVD), which are linked to the workstation. The workstation provides a platform for acquisition/analysis of images and auto-couch motion for repositioning. For collision interlock test, possible collisions are made to check sound alarm and motion interlocks of the system itself, radiation machine (LINAC), treatment couch and OBI console. The isocenters of MVD, KVS and KVD should coincide with the isocenter of the LINAC. The vertical distance from the isocenter to each device and longitudinal/lateral shift of the isocenter should be measured. The isocenter reproducibility is tested after vertical movement of each device. The digital measurement tool accuracy should be tested as a part of mechanical tests. This digital measurement test confirms magnification and accuracy of digital read for MVD and KVD. For image quality tests, the Las Vegas phantom and the Leeds TOR 18FG phantom are used for MVD and KVD respectively. The visible disks in raw and column in the Vegas image determines the contrast and resolution of MVD. The number of disks visible in the Leeds image determines the contrast and the visible line-pair per mm determines the resolution of KVD. **Results:** The procedure has been performed for monthly OBI QA. Only small variations within the acceptable range have been found. **Conclusion:** The suggested QA tests assure reliable portal images for verification of daily patient positioning using OBI. It is very important to set up a standard procedure to provide acceptable clinical service.

SU-FF-T-213

Quality Assurance for the Siemens Multileaf Collimator: A Procedural Review

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Purpose: Many national and international commissions recommend quality control programs for radiotherapy including tolerances and frequency of the tests for treatment units. However, the quality assurance program (QA) for specific Multileaf Collimators is not available. In this paper, we discussed the quality assurance consideration for Siemens MLC and reviewed the QA procedures followed in our institution. **Method and Materials:** QA of the MLC for conformal radiotherapy needs to be redesigned to achieve the required accuracy for IMRT. In general, the MLCs require more stringent

tolerances and more involved QA program. The goal of quality assurance can be summarized as follows.
i) Calibration of Y-jaws to radiation
ii) Optical and radiation field matching
iii) MLC field size calibration
a) Mechanical calibration
b) Optical calibration
iv) Leaf position accuracy and reproducibility
v) Leakage radiation and transmission radiation between leaves and through leaves
vi) Effect of gravity on leaf positions and leakage radiation
vii) Jaw speed verification
viii) Verification of functional and safety interlocks
Some tests are performed at cardinal gantry and collimator angles to verify the effect of gravity and friction on leaf positioning and reproducibility. Besides, the uses of multileaf calibration fixture tool for various procedures discussed. **Results:** A summary of the tests, frequency and their tolerances are provided. However, this is different from the recommendation of AAPM TG40; the tolerances are set with the MLC configurations and limitations in mind. **Conclusion:** A broad quality control program is necessary in particular for progress to continue along the route of conformal and intensity-modulated irradiation techniques. We believe that maintaining stringent tolerance limits are necessary and Siemens MLC fairly maintains such tolerances. In our institution, a comprehensive MLC QA requires about 35 minutes every month and it is a fraction of the time compared to the total machine down time.

SU-FF-T-214

Quality Assurance Of Modern Helical CT-Simulator Scanners: Reproducibility Of Tissue Heterogeneity Curve

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Purpose: Accurate and highly reproducible tissue heterogeneity curve is essential to the proper implementation of tissue heterogeneity correction in imaged-based treatment planning systems (TPS). Tissue heterogeneity curve for a CT-Simulator scanner must be determined at the time of TPS commissioning and at time intervals not to exceed three months. This work investigates the reproducibility of tissue heterogeneity curve over a number of modern helical CT-Simulator scanners and a period of four years. **Method and Materials:** The tissue heterogeneity curve is obtained by scanning a commercially available tissue characterization CT phantom with inserts of different densities. A tissue characterization CT phantom model CIRS062 with 17 inserts covering the relative electron density from 0.19 to 1.51 was used. Five modern GE lightspeed plus helical CT-Simulator scanners purchased within the last four years were investigated. The scanning parameters used were 120 kV, 260 mA and 5 mm slice thickness. After the CT phantom was scanned, a region of interest was drawn in the middle of each insert on the axial image to determine the mean HU (Hounsfield Units) value and standard deviation. The mean HU values were plotted against the relative electron densities. **Results:** To aid in the evaluation, the tissue heterogeneity curves were fitted with two linear equations. The slopes and intercepts were obtained and compared. These curves have almost identical slopes and intercepts within the standard deviation over the stated time intervals and for different but same model CT-Simulator scanners. **Conclusion:** Modern helical CT-simulator scanners give highly reproducible tissue heterogeneity curve over time. This investigation demonstrates the improvement in performance of modern CT-Simulator scanners compared to fourth generation CT scanners. A technique of analysis based on fitted relationship is introduced for the quality assurance of the tissue heterogeneity curve.

SU-FF-T-215

Radiation Leakage From the Electron Applicators in the Varian 21 EX Linear Accelerator

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Purpose: Radiation dose leakage from the applicator is a well-known phenomenon in the electron radiotherapy. This study was to measure such scattered dose and find out its dependences with the angle of obliquity, cutout and applicator size using our clinical 4 MeV electron beam. A piece of lead foil wrapped around the lower part of the applicator could eliminate the dose. The increase of output due to the application of lead can be solved by a simple output correction factor measurement. **Method and Materials:** Calibrated Kodak TL film was used to measure the surface dose and dose at 1 cm depth in a solid water phantom using our Varian 21 EX linear accelerator with 10 x 10 cm^2 applicator and cutout. A film scanner was used to determine the dose. The film measurement was verified with ionization chamber and MOSFET detector. A lead foil of 1 mm thickness was used to wrap the applicator up when needed. **Results:** Peripheral scattered dose was found at about 12 cm away from the field central axis of a 10 x 10 cm^2 cutout. The surface dose was determined to be about 1.5 cGy when 150 cGy was given at 1 cm depth in the phantom (SSD = 100 cm). It is found that the surface dose increased with the angle of obliquity, and with the square cutout size. By warping the lower part of the applicator up with lead foil, such dose was not detectable. **Conclusion:** Peripheral scattered dose outside the applicator of 4 MeV beam was measured and located. Such dose depends on the angle of obliquity, applicator and cutout size. We suggested using a lead foil to wrap the applicator up with an output correction factor to eliminate the dose during the clinical treatment as and when required.

SU-FF-T-216

Radiation Shielding for Helical Tomotherapy

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Purpose: Helical Tomotherapy is an emerging form of radiation therapy treatment which is finding its way into existing and new facilities. The predominant source of radiation to consider for shielding design is from head leakage because of the presence of a beam block. The definition of the head leakage factor in NCRP reports is irrelevant for this machine and there is no accepted way to determine it by measurement. With the increased use in monitor units for treatment typical of IMRT, a more accurate determination of the factor for rotating radiation sources is advantageous in radiation shielding design. **Method and Materials:** The scatter field of the accelerator head is modeled with a function which approximates a Gaussian and convoluted with a point distance function to obtain a parametric expression for the radiation field as a function of distance and angle. Radiation measurements obtained from Tomotherapy were used to determine fit parameters for the parametric expression. Head leakage factors are evaluated at a large a distance from the accelerator to obtain a limiting value appropriate for radiation shielding calculations. An example of the use of the factors is applied to the design of JBCC facilities. **Results:** Head leakage factors were determined for the AP and lateral directions. The factors are ε_{0^o}=1/8,300 and is ε_{100^o}=1/2,600. The shielding of the Tomotherapy facility at the JBCC with concrete required 0.74m for the control area in front of the accelerator and 0.92m for the corridor on the side. With areas interchanged, the shielding for the control area is 1.18m and the corridor is 0.80m. **Conclusion:** A new method of determining the head leakage factor was presented. Due to the radiation anisotropy of the Tomotherapy accelerator, its orientation to protected areas may be an important factor in the consideration of radiation shielding of a new facility.

SU-FF-T-217

Reference Electron Beam Dosimetry Data Set: A Preliminary Analysis

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Purpose: To investigate the feasibility of developing a set of standard percent depth dose (PDD) curves for electron beams to be used when providing quality assurance (QA) checks on machines. **Method and Materials:** A database of PDD data collected on more than 900 machines was used as a source of central axis PDD data. The database consists of curves from Varian (62%), Siemens (26%), Elekta/Philips (8%), Mitsubishi (2%) and GE/CGR (1%) machines. For this study the data was restricted to modern Varian and Siemens machines with data for 5-6 electron energies each. PDD data for each beam was extracted for 10x10 or 15x15 cm cones. The data were fitted to a six-order polynomial to predict PDD from depth of 0.2 cm to approximately 20% of maximum dose providing excellent fits for all data ($R^2 \geq 0.99$). The curves were compared for shape and location on the depth scale for each beam for each machine model. Selected PDD

data were validated by TLD QA measurements at 2 depths in a fixed geometry system. **Results:** The curves were stratified by machine model and nominal energy and agreement was found to be ± 1 mm of the mean curve for all depths between 100% and 20% of maximum dose. Average curves developed were found to depend little on manufacturer. **Conclusion:** With the large database of PDD data measured independently by many physicists on many machines the information is available to develop standards for common machine models with a high degree of accuracy. The standards can be used to review PDD data for QA and to provide information on curve shape when data provided by physicists for QA is sparse.

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SU-FF-T-218

Skin Dose Due to a Supporting Pad in Prone Breast Treatments

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Purpose: To quantify the skin dose on the medial side of the breast due to the use of a foam pad to support the patient in the prone treatment position. **Method and Materials:** A phantom was constructed to measure the skin dose with a parallel-plate chamber. The chamber side of the phantom faced medially so that it faced the pad. The phantom was then treated repeatedly with the pad at various distances from the phantom. A buildup experiment was also performed on the phantom without the pad and with the pad set at 2.5cm away from the surface of the chamber. Performance was assessed by measuring the skin dose as a function of distance and as a percentage of the target dose. It was also assessed by the buildup region created by the pad to the one without a pad present. **Results:** Examination of the skin dose versus the distance to the pad revealed a dependence on distance. This can result in the total dose increasing as much as 50%. The pad when positioned 2.5cm from the breast adds a bolus to the breast of about 3mm on the medial side of the breast. **Conclusion:** This project revealed that skin dose increases through the use of the supportive pad. The experiment however is a worst-case scenario. A normal treatment would have reduced skin dose due to the use of multiple beam angles. In the future, skin dose has to be considered for prone treatments with a support pad.
Conflict of Interest: Funded in part by TomoTherapy, Inc.

SU-FF-T-219

Stability of the Xoft AXXENTTM X-Ray Source During Irradiation in a Goat Mammary Model for APBI

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Purpose: This study evaluated the x-ray output stability of the Xoft Axxent™ Electronic Brachytherapy System while delivering fractionated doses to a Nubian milk goat animal model. **Method and Materials:** Eight balloon applicators were inserted percutaneously into simulated lumpectomy cavities created in the udders of four Nubian milk goats; active and control applicators were inserted in opposite udders. Two goats received spherical applicators and two goats received ellipsoidal applicators inflated to nominal diameters of 3.4 cm and 4.9 cm, respectively. Radiation treatment using 40 kV or 50 kV commenced three days after implantation. Prescription dose was 34 Gy to a point 1 cm from the applicator surface to be delivered in 10 fractions BID for 5 days as for conventional APBI. During the final three fractions for each animal, dose rate was monitored by a Victoreen 451B Ion Chamber Survey Meter located 40 cm from the treated udder. Results: Ten fractions were successfully delivered to each goat within five days. X-ray source performance and dose delivery was very stable during treatments and between different fractions. A flexible radiation shield (which reduced radiation levels around the animals by at least 100x) was positioned to allow line-of-sight between the 451B meter and the treated udder. Radiation levels recorded at 1 second intervals during the treatments were analyzed for dose rate fluctuations and drift. The standard deviations from average dose rates varied from 1.2% for the shortest treatments (225 s) at 50 kV to 3.7% for the longest treatments (1450 s) at 40 kV with an average of 1.9% over all fractions. **Conclusion:** The Electronic Brachytherapy System performed as expected with respect to applicator integrity, controller hardware and software operation, x-ray source lifetime and stability, and flexible shield radiation attenuation. **Conflict of Interest:** Research was supported by Xoft, Inc.

SU-FF-T-220

Standardizing Standards: The Development of Quality Control Criteria for Canadian Radiation Therapy Equipment

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Purpose: To develop a comprehensive, generically formatted set of quality control standards for radiotherapy preparation and delivery equipment in use in Canadian radiation treatment centres. **Method and Materials:** The philosophy behind the development of these standards documents was that they should focus on the standards themselves and not necessarily include descriptions of how the tests are performed. The documents were intended to be brief and unambiguous and, by distributing them through a website, they could be readily updated as experience with new techniques is gained. A generic document format has been adopted. The sections are: 1) Introduction – largely generic 2) Performance Objectives and Criteria – generic 3) System Description – custom 4) Acceptance Tests and Commissioning – largely generic 5) Quality Control of Equipment – largely generic 6) Documentation – generic 7) Table of QC Tests – custom entries in a generic format 8) References and Bibliography – custom. Following detailed review by invited external physicists and members of the Task Group (the authors of this presentation), the draft standard developed was posted on www.medphys.ca for consideration by the Canadian Medical Physics Community at large. The current phase of the project is to solicit and consider the comments from physicists "in the field". These are being fed back into the review process, the standard modified if required and then the standard approved for adoption in Canada. **Results:** To date, the following draft standards have been developed and posted: Cobalt units, linear accelerators, conventional simulators, orthovoltage units, multileaf collimators, electronic portal imaging devices, major dosimetry equipment and remote afterloading brachytherapy systems. **Conclusion:** The largely generic format of the standards has aided clarity of interpretation and expedited the development of the documents. Once finally approved and adopted, these standards may well form an easily monitored component of licensing and accreditation activities applied to cancer treatment facilities.

SU-FF-T-221

Surface Dose Determination with An Interpolation-Extrapolation Method Using EDR2 Films

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Purpose: Kodak EDR2 films have been used for surface dose measurements in radiotherapy. However, with the conventional method, the difference of surface percent doses measured with the film and with chamber could be as high as 5%. In this study, a double extrapolation method was used to correct for the overdose response due to the wrapping papers and film itself so that the surface dose can be accurately determined. **Method and Materials:** In the surface dose measurements, multiple EDR2 films were stacked together and placed on the surface of a 30 cm x 30 cm solid water phantom. Efforts were made to ensure the placement was as air tight as possible. Radiation was delivered, and the doses on the films were measured. Two curves were generated from the measured doses. One is the percent-depth-dose curve for the films, the other is the percent-depth-dose curve for the wrapping paper, where the later curve was interpolated from the film curve. The surface percent dose was derived by extrapolating the paper curve to zero depth. The surface percent dose was also measured using a parallel plate chamber for comparison. **Results:** This method has been applied to the surface dose measurements for various open fields, oblique fields and IMRT fields. It was found that at zero degree gantry angle the surface percent doses measured using this method were in agreement with the chamber measurements to within 2% for both 6 MV and 23 MV photon beams at all the field sizes for conventional and IMRT beams; the agreement was within 3% at gantry angles other than zero

degree. **Conclusion:** An interpolation-extrapolation method has been developed to measure the surface doses using EDR2 films. The accuracy of the method is comparable to that of a parallel plate ion chamber for both conventional and IMRT beams.

SU-FF-T-222

The Analysis of Confounding Factors in Volume Reconstruction of 3DCRT with Spiral Mode CT Simulation

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Purpose: This study is to analyze the difference in reconstructing volume by using phantom model between various settings of axial-mode and spiral-mode computed tomography (CT) simulator for three dimensional conformal radiotherapy. **Method and Materials:** Three phantom balls with different diameters (5.1, 9.9, 12.2 cm) were scanned by a single-row detector CT simulator. The volumes of all phantom balls were reconstructed in the same system. The exactly calculated phantom ball volumes were the baselines as compared to the volumes by the conventional axial CT reconstruction. The reconstructed volumes from the axial-scanning-mode were compared with the corresponding settings of the spiral-scanning-mode in CT simulation, with four different Hounsfield thresholds, three different pitches (1, 1.5 and 2), and four different slice intervals (1, 2, 3 and 5 mm). **Results:** The larger slice width and HU threshold were associated with larger difference between the exactly calculated volumes and reconstructed volumes in axial CT mode. The volume losses were more than 5% for small phantom ball in all axial CT settings. The lowest HU threshold and slice width of less than 5 mm were needed to maintain the volume loss of less than 5% in medium and large balls. As compared to axial scanning, spiral scanning offered the volume reconstruction loss of less than 5% in almost all settings. The exceptions existed in the small phantom ball with the slice interval of 5 mm, spiral pitch of 1.5 and 2 at 50 HU, and slice interval of 5 mm, spiral pitch of 2 at 0 HU. **Conclusion:** Slice interval, spiral scanning pitch and HU threshold were the factors with the impact on the accurate estimation of volume reconstruction by spiral CT simulator. Spiral CT mode was feasible in most scanning settings with the acceptable volume reconstruction accuracy threshold of more than 95%.

SU-FF-T-223

The Effect of Miniphantom Material On Output Ratio In-Air

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Purpose: To investigate the effects of miniphantom materials on output ratio in-air **Method and Materials:** Output ratios in-air were measured for beam energies of 6 MV and 15 MV, for collimator settings ranging from 3×3 to 40×40 cm^2, and radiological depths between 1.83 - 36.6 g/cm^2 for graphite, 1.6 - 33.6 g/cm^2 for copper, and 2.28 - 21.6 g/cm^2 for lead, respectively. The miniphantoms were of cylindrical shape. The lateral dimensions of the miniphantoms (> 4 g/cm^2) were large enough to provide electron equilibrium and small enough to ensure coverage by the beam. Attenuation coefficients for those beam quality were measured with good geometry for the miniphantom materials. **Results:** At 6 MV, the maximum variations of the output ratios with the depths were -0.67%, -0.89%, and -0.66% for graphite, copper, and lead, respectively. At 15 MV, they were -1.68%, -0.84%, and -0.43%, respectively. Output ratios measured with copper and lead at the same radiological depth, e.g., 10 g/cm^2, varied by -0.56% and -0.62% respectively at 6 MV, and -0.84% and -0.93% respectively at 15 MV, compared to graphite, a water equivalent material. Attenuation correction factors varied by -3.62%, -4.76%, and -4.89% at 6 MV, at the depth of 10 g/cm^2, for graphite, copper, and lead, respectively. And they varied by -1.53%, -2.85%, and -2.45%, respectively at 15 MV. Mass energy transfer correction factors of copper and lead, compared to graphite, varied by 6.24% and 9.42%, respectively at 6 MV, and 6.77% and 2.76%, respectively at 15 MV. **Conclusion:** Output ratios measured using miniphantoms made of high Z materials showed variations from the miniphantom made of water equivalent material. For the same miniphantom, output ratio varied with its thickness. These differences can be accounted for by a collimator size dependent correction factor. We have measured various components of the correction factor.

SU-FF-T-224

The Use of Computed Radiography in Radiotherapy

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Purpose: To investigate the feasibility of using Computed Radiography as a film replacement in a radiotherapy department. **Method and Materials:** A computed radiography (CR) system designed for radiotherapy has recently been introduced to the market. The CR system has separate imaging plates designed for KV imaging, low dose portal imaging (1-10mu) and high dose portal imaging (10-400mu). An evaluation of the possibility of using CR for all functions that are typically done with film in a radiotherapy department has been done. This included an evaluation of image quality of the CR system for portal imaging. It also included an evaluation of the CR system for various quality assurance issues such as gantry and collimator spoke shots, light to radiation congruence, and HDR source position accuracy. **Results:** The image quality provided by the CR images was determined by both Oncologists and therapists to be acceptable for use in conventional portal imaging. Images of a contrast resolution phantom were taken with CR, film and an ASi portal imager, and are similar for all three. Quality assurance tests typically done with film can be done with CR imaging techniques. The analysis of spoke shots is possible with the existing tools, but could be streamlined with the development of some analysis software. Similarly it is possible to evaluate the light field vs radiation field congruence with the existing tools in the CR system, but this could also be made easier with some further software development. **Conclusion:** Computed radiography can be used as a film replacement for imaging and QA in a clinical radiotherapy department. **Conflict of Interest:** This work has been supported by AGFA HealthCare

SU-FF-T-225

Utilization of Thebes II Linear Ion-Chamber Array to Calculate Wedge Angle Using a Single Exposure

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Purpose: Thebes II model 7040, a linear array of ion chambers has been utilized in measurement of physical as well as virtual wedge angle using only one exposure. This technique was applied to all available clinical photon energies and various field sizes. **Method and Materials:** Measurements were carried out for the 60^0 motorized wedge in Elekta SL-25, and all four wedges of a Varian Clinac 2100-C accelerators. Wedge profiles at the depth of 10 cm of acrylic phantom were measured for 6MV, 10MV, 15MV, 18MV, and 25MV photons. The wedge angle was measured as a function of field size from 5x5 to maximum wedge field. The source to surface of phantom distance was set at 100 cm. Wedge angle was calculated through an attenuation method described by Schmidt, E-L, et. al[1]. Measured data agreed favorably with the expected wedge angle and was reproducible. Preliminary work performed in computing the effective wedge angle when virtual wedge applied will be presented. **Results:** Results from the motorized wedge in Elekta accelerator measured for photon energies 6, 10, 15, and 25 MV and all clinically relevant field sizes indicate excellent agreement with the largest deviation of 2.7% for the 45 degree wedge in 6MV beam. **Conclusion:** This device, with 47 water proof air ionization chambers of 0.5 cc on a 0.5 cm pitch can provide a simultaneous measurement in real time for the full width of the radiation field for accurate wedge angle computation.

SU-FF-T-226

A Dosimetric Evaluation of a New MOSFET Radiation Dosimeter for Total Body Irradiation

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Purpose: To evaluate the use of a new metal oxide semiconductor field effect transistor (MOSFET) as an in vivo dosimeter for patients receiving total body irradiation (TBI). **Method and Materials:** The dose responses of the MOSFET dosimeters are compared to that of thermoluminescent dosimeters (TLDs) during TBI treatments of 4 patients. Each patient is treated AP/PA with ^{60}Co irradiation, a field size of 44 x 44 cm^2 at isocenter, and an SAD of 338.2 cm. One MOSFET dosimeter and 4 TLD crystals are placed at the entrance and exit of five anatomical sites: head, chest, lung, umbilicus, and pelvis. Additionally, the dosimeters are positioned at a

calibration point in air to normalize the dosimeter readings. The MOSFET dosimeters are read instantaneously with a digital hand held reader, and the TLDs are measured with a TLD reader. **Results:** The measured midline dose rates and calculated treatment times of the MOSFET dosimeters and TLDs are compared. The average deviations of the MOSFETs from the TLDs are 6% at the head, 7% at the chest, 3% at the lung, 1% at the umbilicus, and 4% at the pelvis. The maximum deviation of the MOSFETs from the TLDs is 11.5%, and the minimum deviation is 0.94%. The MOSFET calculated treatment times are within 5% of the TLD calculated treatment times. Three dosimeters failed during the treatments. **Conclusion:** These results show that the new MOSFET dosimeters are an adequate and efficient measurement system for TBI treatments. The cause of dosimeter failure has not been determined as further analysis and experience with the MOSFET dosimeters are necessary. It is recommended that more than one MOSFET dosimeter is used per site for TBI treatment in case of dosimeter failure.

SU-FF-T-227

A Frequency-Domain Approach for Addressing Heat-Transport Problems in Room-Temperature Water Calorimeters

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Purpose: To develop a way to collect and analyze water calorimeter data that enables the use of frequency-domain signal processing techniques for extracting radiation dose signals from waveforms containing artifacts due to conduction and convection. This would provide a convenient, inexpensive way for standards labs to obtain accurate estimates of absorbed dose to water. **Method and Materials:** A sealed-water calorimeter of the Domen design was used in a ^{60}Co beam delivering approximately 15 mG/s. Bridge excitation and voltage measurements were performed with a lock-in amplifier, using a 100 Hz, 1 Vrms sine wave as a reference signal. Square-wave modulation of the radiation beam, achieved by controlling the source shutter, was conducted for shutter periods ranging from 60s to 3600s. For each shutter-period setting, measurements of the bridge imbalance (voltage) waveform were collected at a sample rate of 5 Hz for several hours. The waveforms were then analyzed using both time-domain (midpoint extrapolation) and frequency-domain techniques. All measurements were done at room temperature. **Results:** Severe distortion in the time waveform is observed for periods above 240s, precluding accurate dose estimation by midpoint extrapolation, but correct absorbed dose estimates are nevertheless obtainable via Fourier analysis. At periods below 240s, time-domain analysis converges to the results of Fourier analysis, and both concur with the historical value transferred by an ionization chamber. **Conclusion:** Several standards labs have been able to eliminate convection artifacts by incorporating external refrigeration systems that keep the water temperature near 4ºC. However, this comes at considerable cost, makes the calorimeter bulky and difficult to transport, and does not address the problem of conduction artifacts. Our approach may offer a more portable, robust, and efficient system for direct dose measurements in variable environments.

SU-FF-T-228

A Integrated Approach to Improve Accuracy of Film Dosimetry in TPS Verification

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Purpose: To eliminate negative impacts in film measurement system, which adopt commercially availabe scanner as digitizer, and diminish film's inherent over-response to low energy scatter photons, an integrated approach is proposed to improve total accuracy of film dosimetry. **Method and Materials:** The system is composed of EDR2 radiographic film, polystyrene phantom, auto-processor and ArtixScan 2020 Scanner.A wavelet packet filtering method combining with mid-value filtering is employed to eliminate interference-pattern artifacts, grains drift and high frequency noise, which usually produced by laser scanner based on CCD in film digitizing process and have random characters. In order to reconstruct the original OD image, point-spread function (PSF) is used to deconvolve transmission gray data. Besides calibrating for OD-Dose translation, the approach also integrates a nonlinearity correction method to scanner with Kodak step wedge film to correct the nonlinearity and inconsistency of the detectors' response to film's gray. To reduce film's inherent loverresponse to low energy, a set of coefficients of EDR2 film for Co-60 γ rays in polystyrene phantom is calculated through MC simulation and used to correct film dose in TPS's verification for rotating gamma system. The results from 0.015 cm^3 PTW ion chamber is obtained and used to be the reference. **Results:** Trial validation experiment shows this approach has better linearity, higher sensitivity of OD-Dose response, and excellent agreement (SSD <5% in 21 test points) with those from ionization chamber at corresponding planes in phantom. **Conclusion:** This approach has a potential capability in clinicl to eliminate artifacts and noises in film digitizing process, and then significantly improve total accuracy of film dosimetry. To remove its over-response, the key is to acquire the appropriate correction coefficient for various buildups through experiment or MC simulation, both needing collaboration with other research groups interested.

SU-FF-T-229

A Test of the 3D Scintillation Dosimetry Method for a Ru-106 Eye Plaque Applicator

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Purpose: To describe and test a novel and potentially fast, 3D relative dosimetry method based on the observation of scintillation light from an irradiated liquid scintillator (LS) volume serving simultaneously as a phantom material and as a dose detector medium. **Method and Materials:** The method, named Three Dimensional Scintillation Dosimetry (3DSD), uses visible light images of the liquid scintillator volume at multiple angles and applies a tomographic algorithm to a series of these images to reconstruct the scintillation light emission density in each voxel of the volume. The method is applied to a Ru-106 eye plaque immersed in a LS volume and the reconstructed relative 3D dose map is compared along selected profiles and planes with radiochromic film (RCF) and diode measurements. **Results:** The comparison indicates that the 3DSD method agrees with the relative RCF dose distributions for a small (3 mm high by ~12 mm diameter) part of the volume within 25% for most points. Larger, up to 45 % deviations are observed for fraction of the points due to elongation of the RCF transverse isodose contours, not seen by 3DSD. For a comparison, the spread of the RCF measurements ranges from 10 to 15% within this volume. The method is not accurate close to the edge of the plaque, close to the edges of the scintillator volume and further than ~9 mm from the plaque surface. **Conclusion:** 3DSD shows potential for quick 3D relative dosimetry in a small volume with accuracy and resolution comparable to existent 2D techniques. More accurate determination of the point spread function of the system, of the light scatter within the cell, of the dose-rate and energy related quenching effects and enhancement of the algorithm for partially blocked projections are expected to extend accuracy to larger volumes and closer to the applicator edges.

SU-FF-T-230

Anomaly Characteristics Of Tissue Heterogeneity Curve From Three Commercially Available Tissue Characterization CT Phantoms

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Purpose: Uncorrected treatment plans for tissue heterogeneities can produce errors exceeding 30% of the prescribed dose. Tissue heterogeneity correction is made by acquiring a Hounsfield Units (HU) value versus electron density relationship and applied to imaged-based treatment planning systems. This relationship is determined by scanning a tissue characterization CT phantom containing plugs of different tissues (electron densities). This study investigates the quality and provides up-to-date data on three commercially available tissue characterization CT phantoms (model RMI465, RMI467, and CIRS062) scanned using a modern helical CT-Simulator scanner. **Method and Materials:** These CT phantoms were scanned on the GE helical lightspeed plus CT-Simulator scanner. The phantom model RMI465 has 20 plugs while phantoms model RMI467 and CIRS062 have 17 plugs. The electron density ranges from 0.19 to 1.69. The scanning parameters for the abdomen (120 kV) with set slice thickness of 5 mm were used. Once the axial images of the CT phantom were

acquired, a region of interest was drawn at the central area of each plug and the mean HU value and its standard deviation were determined. **Results:** The plotted HU values versus electron densities show scattered data points. One of the CT phantoms exhibiting inconsistent data may be due to chemical composition breakdown was excluded. Overall, the data points were scattered and hence direct input of measured HU values versus electron densities into the treatment planning systems for interpolation should be avoided. Instead, the data entered into the treatment planning systems should be based on fitted relationships. The data can be fitted with two linear equations. **Conclusion:** The HU values versus electron densities derived from commercial CT phantoms should be fitted before entering into treatment planning systems. The relationship consists of two linear equations with a point of inflection at a relative electron density of 1.0.

SU-FF-T-231

Characterization and Real-Time Optical Measurements of the Ionizing Radiation Dose Response for a New Radiochromic Medium

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Purpose: Radiochromic films, generally used for two-dimensional dose verification, have lately been considered for point-based real-time *in vivo* dosimetry. They have some advantages, including near water-equivalency, over dosimeters used currently. In a recent study, GafChromic® MD-55 showed reasonable performance, but some issues remained unresolved. A new film, GafChromic® EBT, has potential to overcome those issues and is investigated. **Method and Materials:** An optical fibre-based setup, capable of real-time measurements, was used to detect the increase in optical density over 630-640 nm range of the EBT film during and after exposure (6 MV X-rays,Varian 2100 EX). **Results:** Change in optical density for EBT film, measured at the end of exposure to 1.9 Gy, was 7.7 times greater than that of MD-55 film. EBT also exhibited less post-exposure darkening, with a 12.5% increase over 18 hours, compared to 25% for MD-55. Change in optical density during exposure for EBT film was non-linear with time or dose. This was not due to a shift of the wavelength of maximum change in absorbance, which was stable at ~636 nm during the entire exposure to 9.52 Gy. Increasing the spectral window over which optical density calculations were performed had little affect on the non-linearity. The EBT film exhibited a small dose rate dependence for optical density measurements during exposure: standard deviation of change in optical density immediately at the end of a 9.52 Gy exposure increased from 0.9% to 1.8% when a six-fold variation in dose rate was introduced. **Conclusion:** GafChromic EBT film has potential as a radiation dosimeter, including real-time applications, due to its increased sensitivity, decreased post-exposure darkening and spectral stability, but signal non-linearity needs to be investigated further. *This work was funded in part by National Institutes of Health / National Institute on Aging (R21/R33 AG19381).*

SU-FF-T-232

Characterization and Use of MOSFET as In Vivo Dosimeters under 192Ir Irradiation for Real-Time Quality Assurance

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Purpose: To characterize the new microMOSFET and MOSFET linear array from Thomson-Nielson for use under ^{192}Ir irradiation and evaluate their use as dosimeters to verify the delivered dose in high dose rate (HDR) brachytherapy. **Method and Materials:** MicroMOSFETs and MOSFET linear array (5 dose points/MOSFET) response to 192Ir photons were characterized in terms of the intrinsic error, the absolute calibrations, the anisotropy and the catheter factor. Such exercise is essential since the MOSFETs are not water equivalent at these low energies. Secondly, an HDR implant (13 catheters) and treatment plan (Plato, Nucletron) were performed on a realistic prostate phantom. During the CT exams, MOSFETs are inserted in a catheter near the urethra. At the same time as catheter reconstruction, a dose point was associated in Plato to the dosimeter position. Comparisons between the dose calculations of Plato and the measured values were performed. **Results:** Intrinsic errors were found to be 1.05 cGy for the MOSFET array and 0.71 cGy for the microMOSFETs. The calibration factors for 192Ir are higher than for 60Co or higher energies as expected for a Si-based device. The calibration factors are also found to decrease as the cumulative dose to the dosimeters increases. The variation is evaluated at 5 % at 192Ir energy over the course of a treatment (around 10 Gy). The dosimeter anisotropy is within the manufacturer specification and was found to have no impact on in vivo dose measurements. The resulting overall difference between the planned dose and the experimental measurements agreed within 7 %. **Conclusion:** A proof of principle that new microMOSFETs and linear array could be used as in vivo dosimeter for dosimetric QA of HDR brachytherapy treatment was made. At this stage, the major uncertainty might well be the real target volume density as compared to water.

SU-FF-T-233

Clinical Implementation of An In-Vivo Dosimetry System in Conjunction with the RadCalc™ Program

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Purpose: To present the clinical implementation of an in-vivo dosimetry system in conjunction with the RadCalc™ monitor unit calculation program. **Method and Materials:** A wireless PC-based in-vivo dosimetry system (rf-IVD, Sun Nuclear Corporation, Melbourne, FL) was acquired with n-type QED diodes for in-vivo dosimetry for photon and electron treatment verification. A series of acceptance tests to assess reliability of this system for in-vivo dosimetry applications were performed. These included post-irradiation signal stability, dose linearity and angular dependence. As a first step, the system was implemented on a Varian 600C 6 MV beam. Calibration measurements were performed in conjunction with an ADCL calibrated PTW N2333 Farmer-type ion chamber in a solid water phantom. The chamber was placed at d_{max} (1.5 cm) and the diode was placed at the surface of the phantom. Correction factors were determined for tray, wedges, field size and source to surface distance (SSD). The SSD correction factors were obtained for a range of distances (80-120 cm). Field size correction factors were obtained for a range of field sizes (4 x 4 - 30 x 30 cm^2). The RadCalc™ software allows a simple interface to enter the collected data and computes the expected diode reading for each treatment field. **Results:** Preliminary results indicate that the agreement between expected and measured readings is within ±5%. **Conclusion:** In-vivo dosimetry system based on surface measurements using diodes can be effectively implemented in conjunction with the RadCalc™ program, facilitating implementation of this quality assurance tool. Specific action levels have been set for agreement between planned dose and dose determined using diodes for different treatment sites. Future work will include commissioning of the of the in-vivo dosimetry system in conjunction with RadCalc™ for IMRT and electron beam treatment verification.

SU-FF-T-234

Detailed Characterization of the Water-Equivalent Material Virtual Water in High-Energy Photon and Electron Beams

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Purpose: In reference dosimetry for high-energy photon and electron beams a solid phantom offers a number of advantages over water as the reference material including ease of use and positioning reliability. This paper describes the characterization of the material Virtual Water (manufactured by Med-Cal). **Method and Materials:** Ionization measurements were made in Co-60, 6 & 10 MV photons and five electron beams (4-22 MeV). Two techniques were used: i) substitution - Virtual Water slabs displaced water in a water phantom, and ii) direct comparison of ionization measurements in a water and Virtual Water (VW) phantom. Two formulations of Virtual Water were evaluated, having different densities. **Results:** Neither formulation showed exact water equivalence in photon beams – the water/VW ratio varied with the depth of measurement with a difference of over 1% at 10 cm depth. However, by using a density (range) scaling factor very good agreement (< 0.2%) between water and VW at all depths was obtained. In the case of the electron beams a range-scaling factor was also required to match the shapes of the depth dose curves in water and Virtual Water. However, there remained a difference in the measured fluence in the two phantoms after this scaling factor had been applied. For measurements around the peak of the depth-dose curve this

difference amounted to 0.4%. **Conclusion:** The level of water equivalence for Virtual Water is among the best reported for epoxy-resin based materials. The low overall uncertainty on the fluence ratio - estimated to be 0.18% - opens up the possibility of performing dosimetry in a solid phantom with an accuracy approaching that of measurements in water. This is particularly of interest for low energy electron beams (< 6 MeV) where positioning errors in a water phantom can contribute significantly to the overall uncertainty.

SU-FF-T-235

Detective Quantum Efficiency Analysis of An Electronic Portal Imaging Device

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Purpose: To evaluate the portal image quality of an Elekta iViewGT system based on detective quantum efficiency (DQE) measurements. **Method and Materials:** An amorphous silicon based imager was irradiated with 6MV and 18MV beams of an Elekta Precise linear accelerator. The detector panel size is 1024 x 1024 with 0.4 mm pixel size. The source to panel distance is 150 cm. The presampling modulation transfer function (MTF) was computed from angulated slit images. Flat field images were acquired at 2 MUs and 10 MUs for the noise power spectra (NPS) measurements. For the calculation of the DQE, published dose-to-fluence conversion factors were used, namely 1.19×10^7 photons/mm^2 per cGy for 6MV and 3.23×10^6 photons/mm^2 per cGy for 18 MV. [**Med. Phys.** 25, 689–702 (1998)] **Results:** 1**.** The resolution (MTF) for the 6MV beam ($f_{1/2}$=0.25 lp/mm) is comparable to a proto-type flat-panel array [**Med. Phys.** 31, 985-996 (2004)]. The MTF declines for the 18 MV beam ($f_{1/2}$=0.16 lp/mm); 2. The NPS are nearly flat up to the Nyquist frequency for both energies. Fixed pattern noises are present at several frequencies and become less apparent for high MUs due to frame-averaging effect; 3. The DQEs are approximately 1-2% at lower frequencies for both beams. The DQE values are similar for low and high MUs, and fall off rapidly due to decreased MTF at higher frequencies. **Conclusion:** The performance of a clinical portal imaging system has been characterized in terms of MTF, NPS and DQE. Our data demonstrate that this imager is X-ray quantum-limited. The DQE evaluation procedures are being further tested for accuracy, efficiency and robustness. The clinical impact of the MTF, DQE and fixed pattern noise will be investigated further.

SU-FF-T-236

Dose Response of Ion Exchange Resin Beads

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Purpose: To investigate the x-ray dose versus ^{1}H NMR spin lattice relaxation (T_1) response of ion exchange resin beads, with and without ferrous ions. **Method and Materials:** Strong acid cation exchange resin beads (Rohm and Haas, Amberlyst 15 Wet) were rinsed in distilled water and packed in plastic vials. Similar beads were treated to produce a 1 mM ferrous ion concentration inside the beads, then rinsed with distilled water, and finally packed in plastic vials. Sample vials were placed in a water phantom and exposed to 6 MV x-rays from 0 to 100 Gy. The T_1 for each sample was measured in a 1.5 Tesla MRI unit. Beads from two manufacturing lots, Lot 1 and 2, were tested. Density of the bead samples was 1.10 g/cm^3. **Results:** Vials with beads containing ferrous ions exhibited a linear dose versus R_1 (i.e., $1/T_1$) response with slopes of 0.102 and 0.093 sec^{-1}Gy^{-1} for respectively Lot 1 and Lot 2 beads. Vials of Lot 1 beads containing no ferrous ions exhibited a linear dose versus R_1 response with a slope of 0.083 sec^{-1}Gy^{-1}. Vials of Lot 2 beads containing no ferrous ions showed an exponential increase in R_1 of 2.4 sec^{-1} from 0 to 50 Gy with minimal increase in R_1 from 50 to 100 Gy. **Conclusion:** For both bead lots, the beads containing ferrous ions exhibited similar linear dose versus R_1 responses. Beads containing no ferrous ions exhibited significant, but different dose versus R_1 responses. When the ferrous ions are present in the beads, a ferrous oxidation reaction appears to dominate the dose response. The results support the concept of using strong acid cation exchange resin beads containing ferrous ions to create a three dimensional dosimeter which can be evaluated using MRI.

SU-FF-T-237

Dosimetric Evaluation of GAFCHROMIC® XR Type T and XR Type R Films

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Purpose: Recently, two new films models, GAFCHROMIC® XR type R and type T films have been developed by ISP, for the measurement of high dose radiation in interventional radiological procedures. The objective of this project is to determine the dosimetric characteristics such as linearity, time dependence, sensitivity, energy dependence, dose rate dependence and UV light sensitivity of these new film types. A comparison of dosimetric characteristics of these film types with the other commercially available film models is also presented here. **Method and Materials:** The XR type T, type R and MD-55-2 films were exposed to low energy beams from an Oldeft Therapax HF 150T superficial unit and also to high energy beams from a Varian LINAC. The type T films were scanned using a Lumiscan-50 laser scanner and the type R films were read using a GretagMacbeth D19C reflection densitometer. The optical densities of MD-55-2 films were measured with both the scanning techniques for comparison with XR type T and type R films. **Results:** For low energy beams, the type T and R films were found to be approximately 14 times and 6 times more sensitive than MD-55-2 film, respectively. The optical densities of these film types were found to increase by approximately 16% within the first 24 h after exposure and an additional 4% for the next 24 h. No significant changes were found approximately 360 h after the exposure. The energy dependence of the new films for high energies was similar to that of MD-55-2, but at low energies these films show a larger variation of optical density compared to MD-55-2 film. An insignificant effect of UV light on the sensitivities of the new films was observed. **Conclusion:** The dosimetric characteristics of the news films were evaluated and also compared to the other commercially available film models.

SU-FF-T-238

Dosimetry of Small Beams Used in Radiosurgery: A Comparison Between Different Detectors and Monte Carlo Simulation

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Purpose: To compare experimental results from different detectors to Monte Carlo simulation in the dosimetry of small fields employed in the Cyberknife radiosurgery system. The Monte Carlo code has also been used to decide whether protocols that require a 10x10 cm^2 field can be used for dosimetry under reference conditions. **Method and Materials:** Total scatter factors ($s_{c,p}$) have been measured by means of the PTW PinPoint, Exradin A16 and T14P microchambers, Thomson and Nielsen micromosfet, PTW diamond and diode detectors, and MD 55-2 radiochromic films. A Monte Carlo calculation (BEAM code) was used to simulate the Cyberknife linac and to calculate $s_{c,p}$ and correction factors to be applied to raw data for various detectors. Two Farmer-type chambers were also simulated in order to calculate the ratio between k_Q factors for the Cyberknife and of for a standard 6MV linac. **Results:** Monte Carlo simulations gave results in agreement within ±1% with experimental results for $s_{c,p}$, PDD and profiles for collimators above 10 mm. Results for $s_{c,p}$ of smaller collimators (5 to 10 mm) agreed with radiochromic film measurements within ± 2%, while results with ionization chambers and diamond suffer from a systematic underestimation, resolved after application of the Monte Carlo correction factor. Micro-mosfet detectors showed good results as compared to Monte Carlo and radiochromic films, but suffered from poor reproducibility. The PTW diode detector seemed to systematically overestimate $s_{c,p}$ values; for the 5 mm collimator, a value of 0.746 has been obtained versus values in the range 0.67-0.71 obtained with Monte Carlo, radiochromic films, ionization chambers and diamond. The ratio between k_Q factors at different beam qualities is 1.002 ± 0.5%. **Conclusion:** Monte Carlo can be used in the dosimetry of small beams to help solve experimental problems due to the finite dimension and to non-water equivalence of the detectors.

SU-FF-T-239

Enhanced Performance of PRESAGE - Sensitivity, and Post-Irradiation Stability

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Purpose: To improve the dose sensitivity and to control the post-irradiation radiochromic response of PRESAGE™ a 3D dosimeter. **Method and Materials:** One cm plastic cuvettes were filled with formulations of PRESAGE™ that varied in the composition of leuco malachite green (LMG), a radical activator and a dissolution solvent. The dosimeters were irradiated using a Varian 600C linear accelarator with a 4 MV photon beam. The dosimeters were irradiated at doses ranging from 10cGy to 60 Gy (250 cGy/min) and measured on a Hitachi-Perkin Elmer 204 spectrometer at 630 nm. The absorbances were measured 10 minutes after irradiation and up to a week post-irradiation. The sensitivity of PRESAGE™ to room light was investigated by placing dosimeters in a laboratory under constant room light at 22°C for approximately 6 hr and periodically measuring the radiochromic response. **Results:** The radiochromic response at 630 nm was linear from 0 to approximately 30 Gy with a slope of 0.16 OD/Gy and with an error, R^2, of 0.9995. The lower limit of dose measurement of the dosimeter is 10cGy. The stability of the post-irradiation radiochromic response can be varied with minor detectable radiochromic response loss after 7 days (<1%/24 hr) to nearly 100% loss of radiochromic response 24 hr. When exposed to room light the photochromic background increases 0.05 cm^{-1}/ hr. **Conclusion:** The performance characteristics of PRESAGE™ have been enhanced by increasing the sensitivity of the dosimeter. The rate of thermal bleaching post-irradiation can be controlled by varying the ratios of the LMG to the radical activator and quantity of dissolution solvent. The ability to control the rate of losing the radiochromic dose distribution is an important characteristic for a potentially reusable dosimeter. Precautions must be taken to minimize the exposure of PRESAGE™ to room light.

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SU-FF-T-240

Evaluation of a New Calibration Method for In-Vivo Diodes with Sliding Window IMRT Delivery

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Purpose: To evaluate the response of in-vivo diodes for IMRT delivery under new calibration condition. **Materials and Method:** In-vivo diodes (QED p-type, 6-12 MV and 15-25 MV, Sun Nuclear Inc) with model 1131 dosimeter were calibrated with actual patient IMRT (sliding window technique) treatment fields (hereafter referred to as IMRT diodes). A 6-12 MV diode was placed on top of a solid water phantom at 100 cm SSD with an ion chamber (Capintec PR-06) at d_{max}. First a 10x10 static open field was delivered to obtain the ion chamber reference reading. Then an IMRT breast patient's medial field was delivered, and the ion chamber reading was converted to dose based on the reference reading. This dose number was used to calibrate the diode. A 15-25 MV diode was calibrated the same way with an IMRT prostate's PA field delivered. Regular diodes were calibrated to d_{max} dose under standard conditions (100 cm SSD, 10x10 FS). The response of both regular and IMRT diodes under IMRT delivery were measured with a farmer chamber at d_{max} used as reference. **Results:** Diodes calibrated with the new method, i.e. IMRT diodes over-responded by 2.0% for 18 MV photons and 1.0% for 6 MV photons respectively for IMRT delivery when compared with their corresponding regular diodes, indicating IMRT diodes sensitivity increased by about 2.0% for 18 MV photons and about 1.0% for 6 MV photons respectively. **Conclusion:** A new method to calibrate diode for IMRT delivery was presented. The responses were compared with regular diodes. IMRT diodes over-responded when compared with regular diodes by 2.0% for 18 MV photons and 1.0% for 6 MV photons with IMRT delivery. The evaluation of field size dependence, gap dependence and SSD dependence of the diodes for IMRT delivery have also been submitted to this conference.

SU-FF-T-241

Evaluation of EBT GafChromic Film for External Beam Dose Verification

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Purpose: Radiochromic Films are a widely accepted method to measure dose distributions for brachytherapy. Compared to radiographic films they offer a variety of advantages. They are self developing, almost tissue-equivalent and insensitive to daylight. The films mainly used so far had the disadvantage of a low sensitivity to radiation. The new GafChromic EBT film offers a solution to this problem. The purpose of this paper is to prove the application of this new film for verification measurements concerning IMRT and stereotactic radiotherapy (SRT), **Method and Materials:** In order to establish a precise and reliable dosimetric measuring device, it was necessary to investigate the relevant features of the film. After this the films could be applied for dosimetric measurements with 6 MV x-rays using a Siemens Primus linear accelerator. The verification measurements (IMRT and SRT) were done using a µMLC manufactured by 3D Line in combination with the Primus. The films were placed in our multi-purpose Phantom (EasyCube). After irradiation they were scanned using a flat-bed scanner (MicroTek) and compared with the data provided by the treatment planning system Ergo++ using selfwritten MatLab routines. **Results:** The general properties of the film were determined (eg. response, post-irradiation growth of the OD, energy dependence) and compared with the GafChromic HS and radiographic Kodak EDR-2 films. The response of the EBT is 10-times higher than the response of the HS, which so far was the GafChromic film with the highest sensitivity, and 3-times higher than the response of the EDR-2. The measured dose distributions (IMRT and SRT) were in good agreement with the data from the planning system. **Conclusion:** The results of our investigations prove that the EBT is a successful approach for making the advantages of the GafChromic films applicable for external beam radiotherapy.

SU-FF-T-242

Evaluation of Implantable MOSFET Dosimeters for Conventional and Intraoperative Radiation Therapy

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Purpose: To test the applicability and reliability of the manufacturer's calibration of implantable MOSFET dosimeters for use under differing clinical conditions. These include conventional radiation therapy and intraoperative radiation therapy, where the need for sterilizable, wireless telemetric sensors may make these detectors the best candidates for *in vivo* dosimetry. **Method and Materials:** The implantable dosimeters were manufactured and factory calibrated by Sicel Technologies, Inc. We tested these dosimeters for conventional radiotherapy beams, where the detectors were placed in a phantom and exposed to 20 treatment fractions with daily doses of 1, 2, or 4 Gy. We also tested the detectors for use in HDR-IORT, where the detectors were placed in a constant-temperature (37°C) water phantom and irradiated with an HDR Ir-192 source with single treatment fractions of 10, 12.5, or 15 Gy. **Results:** Under calibration conditions with conventional radiotherapy beams, we found the dose measured by the detectors using the manufacturer's calibration to be within ± 3% of the delivered dose, with a standard deviation of 2%. Preliminary results support the robustness of the calibration for conventional radiotherapy beams with both higher and lower daily doses, with an increase in error as the daily dose deviates from the calibrated dose. When an HDR Ir-192 source was used, the measured dose showed a linear deviation from the delivered dose due to differences in energy, dose rate, and total dose per fraction. These results suggest the need for additional correction factors when these detectors are used for HDR-IORT and most likely also for IOERT. **Conclusion:** We have verified the manufacturer's calibration of these dosimeters for conventional radiotherapy. With additional correction, these dosimeters appear to be an ideal choice for IORT. **Conflict of Interest:** ASB has a sponsored research agreement with Sicel Technologies, Inc.

SU-FF-T-243

Evaluation of MicroMOSFET Dosimeter For Low Dose Measurement of I-125 Seed

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Purpose: MicroMOSFET detectors have been used in dose measurement for high dose rate brachytherapy sources. In terms of dose characterization for low dose rate seeds, we report our study of using microMOSFET detector for radial dose measurement of ^{125}I seed in solid water phantom, for low doses down to 1cGy at distances out to 6cm. **Method and Materials:** Two high sensitivity microMOSFET detectors (Thomson-Nielsen model TN1002RDM, 1mm wide, 0.9mm thick) were positioned at discrete points along the transverse axis of a ^{125}I seed (Implant Sciences model 3500) of air kerma strength (NIST traceable) of 6U in a solid water phantom (RMI model 457, 30 x 30 x 20 cm^3). One detector was below the seed at 6.115cm for 21 hours. The second detector was above the seed at 0.985, 1.985, 2.985 and 3.985cm for 1.5, 2, 4 and 13.4 hours, respectively. The estimated dose rates ranged from 6.2 down to 0.05 cGy h^{-1} and accumulated doses ranged from 9.3 down to1cGy, at 0.985 and 6.115cm, respectively. The signals were read using a mobileMOSFET system with high bias voltage setting. The reading (mV) for 0.985cm distance was used to calibrate the MOSFET sensitivity in mV/cGy, based on the dose value (cGy) calculated using the TG43U1 recommended parameters. **Results:** The microMOSFET sensitivity was 32.4 mV/cGy. The dose rates in cGyh^{-1} were determined at the measurement distances. The specific dose rates in cGyU^{-1}h^{-1} were compared with those generated from TG43U1 recommended parameters. General agreement is observed. **Conclusion:** The high sensitivity microMOSFET dosimeter with high bias voltage is suitable for ^{125}I seed low dose measurements with dose rates as low as 0.05 cGy h^{-1}. It is promising for characterization of low dose rate seeds, and for in-vivo dose monitoring during ^{125}I seed interstitial implants. **Conflict of Interest:** Free ^{125}I seed from Implant Sciences Corporation.

SU-FF-T-244

Investigation of Anomalous Recombination Behaviour in Cylindrical Ionization Chambers

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Purpose: Measurements using air-filled ionization chambers must be corrected for the effect of ion recombination. In recent years a number of authors have presented data for cylindrical and parallel chambers that do not agree with the standard Boag theory. An experimental investigation was carried out to look at the possible mechanisms that have been proposed for these deviations. **Method and Materials:** Four different Farmer-type chambers - PTW30001, NE2571, NE2581, Exradin A12 – were used to look at how the recombination behaviour depended on: i) chamber type; ii) continuous or pulsed radiation; iii) dose per pulse; iv) modality (photons or electrons). Three radiation sources were used: i) Sr-90 check source; ii) Co-60 beam; iii) Elekta *Precise* linac. **Results:** It was found that all four chamber types showed similar non-linear behaviour at polarizing voltages > 250 V using a low-doserate Sr-90 check source. This was a little surprising considering the significant differences in chamber design for these types. Also, all chamber types showed a difference in the shape of the 1/I vs 1/V plot for opposite polarities – the chamber signal was larger when collecting negative charge - indicating that the effect may be due to free-electron collection and/or charge multiplication. In the linac measurements no difference in behaviour was seen between photon and electron beams (as expected) but the non-linear curvature and difference between polarities was only seen at low dose per pulse values (< 0.02 cGy). Stem and cable irradiation were also investigated and found to be insignificant. **Conclusion:** Deviations from classical Boag recombination theory have been observed for "well-designed" Farmer chambers in a range of photon and electron beams. Measurements to date cannot single out one mechanism as the primary effect but indicate that insulator/stem irradiation and free-electron collection are not significant.

SU-FF-T-245

Microdosimetry Using Special Type PAG Dosimeter With 4.7 Tesla Small MRI Scanner

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Purpose: To demonstrate the capability of gel dosimeters to determine the dose in the microdosimetry range and to produce special type gels.
With high signal to noise ratio and less susceptible to oxygen from the air and hence reducing the impact of one of the most hindering parameters in gels preparations. **Method and Materials**: Acrylamide-gels were prepared in argon-degassed water and gelatin. The irradiation polymerization induced provides a 3D map of energy deposited, which can be determined by using MRI-scanner. A Bruker type small animal MRI-scanner of 4.7 Tesla magnetic field and 10 cm core is used. An image of the inverse of T2 map was then made by use of a fitting algorithm. A formulation for clear gel was made by changing the monomer concentration to about 20 %T (Total monomer concentrations) and 5 %C (cross linker concentrations).
Results: Pixel size of 59 μm x 59 μm x 1 mm was obtained using a 4.7 T MRI-scanner. Scanning time averaged approximately an hour for a 512x512 image.
Compared to a standard 1.5 T scanner, the improvement in pixel size represents a 15-fold improvement. A small pixel size means improved spatial dose resolution of the gels. High T and low C concentrations improves signal to noise ratio. Dose beam profiles and depth dose curves for 6 MV beams are found to be in agreement with ionization chamber measurements. Results also indicate that oxygen diffusion through the gel container decreases with depth. In using gel dosimeters for more accurate dose resolutions this differential oxygen diffusion through the gels should be considered. **Conclusion:** Gel dosimeters can be used as microdosimeters. Applications for microdosimetry include radiobiology and future radiotherapy such as micro-beam type radiotherapy. The further implications of clear gel formulations and increased magnetic field usage for high pixel resolution warrant additional investigation.

SU-FF-T-246

Novel ZnO Nanotips: Potential Nanomaterials for New Generation of Radiation Detectors

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Purpose: Current dosimetry technology is limited by large detector size (ion chambers), complex handling processes (TLDs), energy dependent and limited dynamic range (films), and thermal noise and low sensitivity (narrow bandgap semiconductor-based dosimeters). Wide bandgap materials have lower background carrier concentration and better temperature stability. ZnO is an emerging wide bandgap semiconductor with a direct bandgap Eg~3.30 eV at room temperature. ZnO is biocompatible and significantly more radiation-hard than Si, GaAs, or GaN. Thus, nanoscale ZnO is particularly suitable for long term *in vivo* therapeutic X-ray and γ–ray measurements. Here, we report our preliminary investigations of ZnO nanotips for potential medical dosimetry applications. **Method and Materials:** High-quality ZnO nanotips were grown on Si substrates by metal-organic chemical vapor deposition. The as-grown ZnO nanotip samples (n=20) were irradiated using 6 MV, 15 MV, 9 MeV, and 20 MeV photon and electron beams on a VARIAN CLINAC 21EX. The irradiated samples were analyzed using X-ray diffraction (XRD), field emission scanning electron microscopy (SEM), photoluminescence spectroscopy (PLS), and sheet resistance measurements to characterize the radiation effects. **Results:** Irradiated ZnO nanotips were found to exhibit identical morphology and functionality as the as-grown ones without observable lattice damage or defect. XRD data showed no change in the intensity or the full width at half maximum (FWHM) of the peaks. The nanotips maintained the primary c-axis orientation, further peaks other than ZnO (002) – (004) doublet and substrate Si (400) were not observed, indicating absence of secondary phase formation or change in structure. Particularly, they maintained good electrical, optical, and crystal properties, the key to make X-ray and γ–ray detectors based on ZnO nanotips. **Conclusion:** ZnO nanotips are a promising new generation of nanomaterials with great potentials in nano-electronics, nano-photonics, high-resolution real-time *in vivo* dosimetry, integrated dose measurement by implantation, and microbeam calibration and profiling.

SU-FF-T-247

Performance of Two Commercial MOSFET Systems at Low Doses in and Out of Field

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Purpose: Some applications in clinical dosimetry require dose measurements in the 1-10 cGy range, such as in vivo dose verification measurements of critical structures that are near the field edge shielded by a jaw, block, or MLC leaf. Since such dose results from scatter, the spectrum is different than in the field. In IMRT, even infield measurements can be underneath an MLC leaf and therefore subject to a different spectrum for part of the irradiation.
The goals of this study were to investigate 1) the repeatability and reproducibility of MOSFET measurements in the 1-10 cGy range; and 2) the impact of the different energy spectrum outside the beam on the dose response. **Method and Materials:** Dose measurements were performed on an 18 MV clinical linear accelerator using two commercial systems (Thomson Nielsen AutoSense and mobileMOSFET) both operated in high sensitivity mode. Measurements were made on the central axis and out-of-field along a profile extending perpendicularly from the center of a field edge. Absolute dose was measured with a calibrated Farmer chamber. **Results:** The AutoSense device was able to measure doses down to 5 cGy with a repeatability of 5.8% (all numbers refer to1 SD) using high sensitivity detectors. The mobileMOSFET device measured at 1 cGy with an average repeatability of 4.8 % for high sensitivity detectors and 7.7 % for standard detectors. Reproducibility was 3.8% and 4.2%, respectively.
MOSFET response outside the field increased with increasing distance from the field edge generally up to 8 % at 4.8 cm. Reproducibility for this location was also about 8 %. **Conclusions:** The commercial MOSFET devices AutoSense and mobileMOSFET have been shown to reliably measure doses down to 5 cGy and 1 cGy, respectively. MOSFET response outside the beam is increased close to the measurement uncertainty.

SU-FF-T-248

Perturbation Factors for the Plane-Parallel NACP02 Ionisation Chamber in Electron Beams

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Purpose: To calculate perturbation factors, p_{wall} and p_{cav}, for plane-parallel ion chambers in electron beams, and to investigate their origin. **Method and Materials:** Current dosimetry protocols for clinical electron beams (AAPM, IAEA, IPEM) recommend the use of plane-parallel ion chambers, such as the NACP-02. These protocols describe how dose–to-water calibration factors, $N_{D,w}$, are used to derive dose to water from ionization measurements in water or plastic phantoms. These factors implicitly include chamber perturbation factors for the non-medium equivalence of the chamber walls and cavity material, p_{wall} and p_{cav}. The perturbation factors are currently assumed unity for well-guarded plane-parallel ion chambers. In this work we have used the Monte Carlo (MC) code EGSnrc to calculate perturbation factors in water, plastics and graphite (used in standard labs) for electron beams ranging from 4-20 MeV for the NACP-02 ion chamber. The MC model was first validated against measurements of chamber response in a solid slab phantom where thin slabs of different materials (plastics, Al, Cu) could be brought in close contact with the ion chamber. In addition, stopping power ratios, medium-to-air, were calculated for clinical and calibration electron beams. **Results:** The agreement between calculated and measured ion chamber response in the slab phantoms was within 1%. Cavity perturbation factors, p_{cav}, for the NACP-02 chamber were found to be within 1% of unity within statistical uncertainty (0.2%). Wall perturbation factors, p_{wall}, for the energy range 4-20 MeV were found to vary from (1.7±0.2)% to (0.2±0.2)% for the NACP-02 chamber. Stopping powers, water-to-air, were found to differ by up to 0.5% from the currently recommended values (Burns et al 1996). **Conclusion:** Electron perturbation factors for the NACP-02 plane-parallel ion chamber were found to differ significantly from unity, which is the currently assumed value.

SU-FF-T-249

Small Electron Field Cutout Output Factors Measured Using a 2D Ion Chamber Array Compared to Radiographic Film

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Purpose: To compare the electron cutout output factor (COF) of small fields measured by two methods: radiographic film (Kodak X-Omat V) and the Seven29 (PTW) 2D small volume ion chamber array. **Method and Materials:** The COFs for four small electron fields were measured on a Varian-2100C accelerator with a 10 cm x 10 cm cone at 6 MeV. Radiographic film and Seven29 array ion chamber were set perpendicular to the central axis of the beam. The film and effective point of measurement for the 2D array were both set at d_{max}. Solid water was used for build up in both cases, and 100 cm SSD was set at the top surface of the solid water. The data were measured using 10 to 400 monitor units (MU) for Seven29 and 30 to 200 MU for the film. The open 10 cm x 10 cm insert data from film measurement was used to compute the film parameters of maximum optical density (OD) and sensitivity based on a single hit model. These parameters were used later to convert the measured cutout data from OD to dose for the COF calculation. The OD was read from a Digital Densitometer II. **Results:** The Seven29 ion chamber array behaved linearly as a function of MU as expected, which provided an identical COF regardless of the number of MU's used (less than 1% difference). The COF results from the Seven29 and from film measurements showed a maximum difference of 1.6%. **Conclusion:** The 2D ion chamber array can be used to measure the COF for a small electron fields. Using the Seven29 to measure small field COF will save measurement time compared to using film dosimetry, and in addition, this is also beneficial to filmless departments.

SU-FF-T-250

Small Field Dosimetry Using a Series of Customized Exradin T11 Prototype Ion Chambers: Under-Response Due to Electron Fluence Perturbations

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Purpose: To investigate the suitability of custom-made small volume plane-parallel ion chambers for accurate dosimetry of small photon fields. **Method and Materials:** A series of four plane-parallel chambers, based upon the Exradin T11 chamber, with varying active volume diameters (2,4,10 and 20mm) and constant air cavity dimensions (2mm electrode separation and 30mm diameter) were used to measure relative dose factors at central axis for circular (0.5 to 4cm diameter) and square (5 and 10cm) 6MV X-ray fields. Other detectors (MOSFET, radiographic and radiochromic film, pin-point ion chamber) were used for intercomparison purposes. Experimental conditions were modeled using BEAMnrc to analyze the ion chamber air cavity's influence on the dose scored in the air cavity as compared to water. **Results:** A large discrepancy was observed between all detector types in the 0.5mm field, where the smallest plane-parallel chamber yielded a signal 40% lower than radiochromic film. BEAM results confirmed that an under-response is expected in this chamber. Scoring planes within the air cavity indicate a decreased secondary electron fluence near central axis in air (compared to water), which corresponds to the area occupied by the collecting electrode. There were no significant differences in electron/photon energy spectra or angular distribution due to introduction of the air cavity into the medium. Correction factors for the experimental measurements were calculated based on differences between dose scored in air and in water. The 2mm diameter chamber requires correction factors of 1.29, 1.36 and 1.75 for 5,10 and 15mm fields respectively. These correction factors were also found to increase linearly with increasing cavity thickness. **Conclusion:** In order to achieve accurate dosimetric measurements in small fields, correction factors must be applied to the measurements of plane-parallel ion chambers. These large correction factors make small-volume plane-parallel chambers with large guard rings unsuitable for small field central axis measurements.

SU-FF-T-251

Small Volume Dosimetry with Multiple Scintillation Probes
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Purpose: To build a novel matrix dosimeter with high sensitivity, good precision and reproducibility based on plastic scintillation dosimetry. This dosimeter possesses excellent water equivalence as well as linearity to dose, dose rate and energy. **Method and Materials:** A dosimeter was built by coupling scintillating fibers, chosen for their high collection efficiency, to clear optical fiber. Light measurements were performed with a color CCD camera in order to compare two techniques to remove the stem effect caused by Cerenkov radiation inside the optical fiber: background subtraction and chromatic filtering. Background subtraction is self-explanatory while chromatic filtering uses light at two different wavelengths (the green and blue channels of the CCD) to remove the undesired Cerenkov radiation. Irradiations were performed at 6 MV for various doses and field sizes. **Results:** The dark images of the camera are uniform and variation between pixels represents less than 0.7 % of the signal produced by a dose of 10 cGy. Stem effect caused by Cerenkov radiation ranged from 5 % (5×5 field) to 35 % (30×30 field) of the total signal. Chromatic filtering and background subtraction both allow to extract from the signal the stem effect with a similar precision. Linearity of the system was validated down to 2.5 cGy (1.31 % standard deviation) with 0.0055 cm^2 probes. At 10 cGy the standard deviation dropped below 0.6 %. Depth dose curves were also measured with a precision below 1 % compared to ionization chamber measurements. **Conclusion:** Chromatic filtering removes the necessity of a second optical fiber for background subtraction, therefore increasing the spatial resolution while maintaining a precision below 1 % for most of the dose range. The CCD camera allows more than 150 detectors in its field of view, which can be used in water, in phantom or *in vivo*.

SU-FF-T-252

Spatial Dose Distributions in Solid Tumors From 186Re Transported by Liposomes Using HS Radiochromic Media
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Purpose: To establish a protocol for directly measuring spatial dose deposition and activity distribution of beta particles emitted by Re-186 transported by liposomes in a HNSCC Xenografts in Nude Rats using HS GafChromic dosimetry media. **Method and Materials:** Nude rats (n=3) at 4–5 weeks age (75–100 g) bearing a tumor with an average volume of 1.73±0.37 cm^3 were injected intratumorally with 0.29±0.05 ml of 18.5±2.7 MBq (0.50±0.09 mCi) ^{186}Re-liposomes, which contained 4.0±0.7 mg of DSPC and cholesterol. The ^{186}Re-liposome dose was equally divided and delivered to several separate locations of the tumor. SPECT and CT images in vivo were acquired using a micro-SPECT/CT scanner. The rats were sacrificed six hours after liposome injection, and tumor lobes were excised and sectioned in slices (3 mm thickness). HS films were placed between each slice and the tumor lobe was reassembled to its original shape. Film calibration was performed between 0-40 Gy using ^{60}Co γ rays. Film response was measured using a flatbed scanner in 36 bits RGB transmission mode. Dose distributions were extracted from the red and green components. **Results:** The 2D spatial dose distributions are highly heterogeneous with dose regions above 40 Gy. Dose gradients up to 40 Gy in distances smaller than 2 mm in the center of the slice tumor were found. While comparing dose distributions between the 3 different tumors, significant differences in the volumes (larger than 30%) covered by the isodose curves of 1 Gy were observed. **Conclusion:** The method to measure direct dose distributions produced by Re-186 transported by liposomes using GafChromic HS film has proved to be adequate for the large dose gradients produced. The use of the different components of the scanned image (red and green) allows us to extend the sensitivity range of the HS film without loss of precision.

SU-FF-T-253

Surface and Implanted Dosimeters: From a Phantom to Patients
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Purpose: Empirical dose measurement with physical detectors is an essential aspect of quality assurance in radiation therapy. Factors such as patient setup, treatment plan error, and physiologic motion work to degrade the accuracy of dose delivery in moving from *in vitro* to *in vivo* dose measurements. **Method and Materials:** This analysis draws from published measurements with diode dosimeters and the authors' experience with an implantable dosimeter system. The spread in measured values for three situations will be evaluated: (1) a solid-state dosimeter on a fixed phantom with a single field exposure, (2) a solid-state dosimeter attached to the skin surface of a patient, (3) a solid-state dosimeter implanted into the GTV of a tumor for the full course of external beam treatment. **Results:** Histograms plotted for the three measurement situations show an increase in the variance of recorded values in moving from a fixed phantom to the interior of the patient. In particular, data from implanted sensors for breast and prostate patients both show a substantial number of dose deviations (from the treatment plan) above 5% and also at 8% and above. In addition to daily variations in delivered dose, with an essentially Gaussian character, offsets from a mean of zero were seen in the implanted dosimeter data. **Conclusion:** This study highlights the chain of approximations occurring between the last empirical check of dose accuracy, at the machine level, and the actual delivered dose at depth in the patient. The data from the three evaluation setups is sensible in that one finds a series of expanding Gaussian distributions in going from a very well controlled to a less well controlled setup. The frequency of errors in excess of 5% for sensors at depth in patients suggests that clinically relevant deviations in dose at depth may be common.

SU-FF-T-254

The Development and Testing of a Prototype Three-Dimensional Wedge for Whole Brain Radiation Therapy
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Purpose: Whole brain radiation therapy (WBRT) is the standard treatment for >2 brain metastases, and often used in conjunction with stereotactic radiotherapy for 1-2 metastases. The use of open fields (conventionally used for WBRT) leads to higher doses to the brain periphery with lower doses near the brain center. These dose variations potentially compromise treatment efficacy and translate to increased side effects. The goal of this research was to design and construct a 3D 'Brain Wedge' to compensate dose heterogeneities in WBRT. **Method and Materials:** Radiation transport theory was invoked to calculate the desired shape of a wedge to achieve a uniform dose distribution at the sagittal plane for an ellipsoid irradiated medium. A wedge was machined based on the calculation results. Three ellipsoid phantoms, representing the mean and ± two standard deviations from the mean cranial size were constructed, representing 95% of the adult population. Film was placed at the sagittal plane for each of the three phantoms and irradiated with 6MV photons, with the wedge in place. Optical density to dose calibrations were conducted following IMRT quality assurance procedures, for 6 MV photon beams. **Results:** The calculations yielded a smooth 3D wedge design to account for the missing tissue at the peripheral areas of the brain. Isodose plots for the three phantoms demonstrated the feasibility of this wedge to create a homogeneous distribution with similar results observed for the three phantom sizes, indicating that a single wedge may be sufficient to cover 95% of the adult population. **Conclusion:** A 3D wedge has been developed based on transport theory with the aim of creating a uniform mid-plane sagittal dose distribution for WBRT. A prototype wedge was machined and experimentally validated. **Conflict of Interest:** Partially supported by Enhanced Oncology Systems and the AAPM Summer Undergraduate Fellowship Program.

SU-FF-T-255

The Dosimetric Characterization of the Performance of the One Dose MOSFET Dosimeter in the Buildup Region of a 6 MV Photon Beam
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Purpose: To characterize the performance of the One Dose MOSFET dosimeter in the buildup region of a 6 MV photon beam. **Method and**

Materials: The depth dose curve in the buildup region was measured in a polystyrene phantom using One Dose MOSFETs, a PTW parallel-plane (p-p) ion chamber, and thermoluminescent dosimeters (TLD) (rectangular chips 0.5 mm thick). The One Dose MOSFET dosimeters were pre-calibrated in a Cobalt beam under full build-up conditions. Calibration factors were supplied by the manufacturer and auto-corrections applied for SSD, field size and modality. Our polystyrene phantom was arraigned so that intermediate thickness of material was applied to the surface without changing the SSD (100 cm). Surface dose measurements were made with the MOSFET and TLD placed directly on the phantom. Radiochromic (RC) film, approximately 0.25 mm thick, was used for fine-step measurements for the first few sub-millimeter steps from the surface. The percentage depth doses (PDD's) were measured to a depth of 5 cm. **Results:** The measured relative depth doses were normalized at their respective maxima. The TLD's and One Dose MOSFETs over-estimated doses at very shallow depths compared to the p-p chamber. The thermoluminescent dosimeters approximated the shallow depth dose better than the One Dose dosimeter. There was a plateau present in the TLD and MOSFET PDD data close to the surface, suggesting an inherent dosimeter buildup thickness of approximately 0.5 and 1.5 mm respectively. Beyond this region, there was good agreement of the three dosimeters in representing the PDD characteristics of a 6 MV photon beam. **Conclusion:** The One Dose MOSFET system can clinically represent the dose under appropriate buildup conditions but overestimates the surface and sub-surface (< 1.5 mm) doses.

SU-FF-T-256

The Effects of Pre-Irradiation On Ionization Chambers Used in Radiation Therapy

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Purpose: To investigate the effects of pre-irradiation on settling (stabilizing) behaviour of a variety of ion chambers, and relate this behaviour to chamber design. Chambers without pre-irradiation can produce errors of up to 1.5%. **Method and Materials:** Data was collected for a large number of common ion chambers, which were induced to display maximum settling behaviour. The chamber regions generating this behaviour were identified through the use of lead shields. Responses to six radiation qualities were measured. Radiographs of the chambers provided insight into some of the physical sources of settling behaviour. **Results:** Ion chambers require exposure to radiation for settling to occur. Maintaining bias on the instrument is not sufficient. Different models display different settling characteristics, but chambers of the same model can also display a variety of responses for both the difference between initial and equilibrium readings and for total settling time. The internal structure of the stem was the source of much of the observed settling behaviour. This is a temporary, reversible effect and is not related to permanent radiation-induced damage in electronic devices. Radiographs provided insight into physical sources of settling behaviour, particularly the extent of ion chamber guarding and the proximity of insulating material to the active air volume. Most models of Baldwin-Farmer ion chambers show time-dependent settling behaviour independent of beam quality, but exposure-dependent behaviour was observed for one model. **Conclusion:** Settling behaviour varies significantly from model to model, and even chamber to chamber. Ratios of initial reading to settled reading can vary by up to 1.5% over 30 minutes, although differences of 0.5% over 20 minutes are more typical. Settling behaviour for individual chambers is similar in either air or water, and quality independent. Pre-irradiation of an ion chamber is essential to avoid the introduction of significant error into photon beam measurements.

SU-FF-T-257

The Study of the Dosimetric Properties of 'RadGel', a New Dosimeter for Three-Dimensional Gel Dosimetry

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Purpose: The development of advanced radiation treatment techniques such as IMRT has prompted an immediate need for a dosimetry system that can provide accurate and convenient measurement of complex three-dimensional (3D) dose distributions. Gel dosimetry has proved a promising candidate, but present gel-dosimeters are still not in widespread routine clinical use. In this work we investigate the dosimetric properties of a new 3D dosimetry material, RadGel™, which has potential for application in radiation therapy. **Method and Materials:** Samples of RadGel™ contained in optical cuvettes (1cmx1cmx5cm) were irradiated in a series of experiments to determine sensitivity to dose, dose rate, energy, and stability of response with time post-irradiation. Pre and post irradiation measurements were made of the optical-density profile along the long axis of the cuvettes using a custom laser scanning system at 632nm. The radiation induced spectral optical density (OD) change of RadGel™ was also measured by a conventional spectrophotometer. **Results:** The spectrophotometric measurements indicated that peak radiation induced OD change occurred at ~600nm (FWHM ~100nm). A linear relationship was observed between OD changes and dose, and negligible dependence on dose rate. OD measurements a week after irradiation revealed significant degradation of optical response compared with scans 24 h post irradiation, but the timescale of these changes is still much improved from existing non-scattering 3D dosimetry materials. **Conclusion:** The RadGel™ material has several attractive qualities for 3D dosimetry. In particular RadGel™ is more robust than established non light-scattering 3D dosimeters to exposure to air and water. Together with an improved stability of response with time RadGel™ appears a practical and convenient material. Further tests are required on larger volumes of RadGel™ to determine true potential.

SU-FF-T-258

Two-Dimensional (2D) Ion Chamber Array for Radiation Dose Verification Including IMRT

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Purpose: Dosimetry in modulated fields such as soft-wedges and IMRT is often difficult and inaccurate due to temporal and spatial fluence variation. It requires two-dimensional (2D) detectors that should be independent of beam energy, dose rate, dose, and depth. Ion chambers provide these criteria and hence a 2D ion chamber array is evaluated for dosimetry in radiation therapy. **Method and Materials:** A 2D array from PTW of 27x27 parallel-plate ion chambers embedded in 5 mm of PMMA is used. The chambers are 5x5x5 mm^3 and are equally spaced at 10 mm on center. The device provides absolute dose with a resolution of 1mGy/min and includes software for dose and image verification in complex fields. Open beam, wedge fields (physical and soft), and IMRT beam verifications were performed on a linear accelerator that was interfaced to an Eclipse TPS. IMRT dosimetry was compared with film and other devices. **Results:** The 2D-array provides the unique opportunity to measure beam profiles in any gantry angle and 2D-wedge profiles of hard and soft wedges. Accuracy was verified to within ±1%. For IMRT fields the device is robust and measures absolute dose as well as dose in any plane. Being an ion chamber device the results are more reliable and can be taken as a gold standard. **Conclusion:** This device is easy to use, robust and provides highly accurate dose and dose rate measurements. Data is energy independent and ideally suited for complex dosimetry tasks such as IMRT and wedge verification. This device can also be used for other routine tasks, like daily QA, wedge checks, dose calibration and IMRT dosimetry. **Conflict of Interest :** Szeglin, Schuele, and Barker employees of PTW.

SU-FF-T-259

Use of Radiochromic Films for I-125 Seed Dosimetry In Solid Water

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Purpose: To evaluate the use of two new models of high sensitivity radiochromic film, GAFCHROMIC® EBT and XRT, for I-125 seed dosimetry from 0.1 cm out to 5 cm. **Method and Materials:** Experimental films were positioned in contact with or at a distance of 0.5 or 1 cm from the ^{125}I seed (Implant Sciences model 3500) in solid water phantom. A multiple film technique was employed, with the product of the air kerma strength and exposure time ranging from 5 Uh to 5500 Uh, using four seeds with NIST traceable air kerma strengths of 7 U. A series of 25 calibration films of each model were exposed to one ^{125}I seed at 0.5 cm distance, one at a time. A CCD camera based microdensitometer, with interchangeable

green (520nm) and red (665nm) light boxes, was used to scan all the films with 0.2 mm pixel resolution. The dose to each calibration film center was calculated using the air kerma strength of the seed (incorporating decay), exposure time and TG43U1 recommended dosimetric parameters. Based on the established calibration curve, dose conversion from net optical density was achieved for each film model and light combination. **Results:** 2-d isodose rate (in cGy/Uh) curves were plotted and compared among the film model and scanning light combinations. Radial dose function and anisotropy function were also determined. The results obtained from two film models corroborate each other. We found general agreement with the TG43U1 recommend values of dosimetric parameters. **Conclusion:** Radiochromic film dosimetry using GAFCHROMIC® EBT or XRT models is feasible and accurate in determining 2-d dose distributions around low dose rate ^{125}I seed. It is a viable alternative to TLD dosimetry for ^{125}I seed dose characterization. **Conflict of Interest:** Prototype GAFCHROMIC® EBT and XRT films from ISP.
Free I-125 seeds from Implant Sciences.

SU-FF-T-260

A Higher Accuracy Electron Beam Model Based On Large Field Measurements

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Purpose: To commission the beam model for electron treatment planning with Monte Carlo 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. Monte Carlo treatment head and water phantom simulations were done with the EGSnrc system using the BEAM and DOSXYZNRC user codes, respectively. The measured data was used to estimate source and geometry parameters, some previously inaccessible in treatment head simulation, including incident beam direction, scattering foil thickness, offset of the secondary scattering foil and monitor chamber from the beam axis, and the distance separating the monitor chamber from the primary scattering foil. Parameter estimation relied on a published, comprehensive analysis of the sensitivity of the measured quantities to source and geometry parameters. **Results:** Dose distributions calculated with this large-field commissioning approach generally compared to 2%/2 mm with diode measurement. Larger discrepancies, as large as 5 mm present at a couple beam energies, were limited to the beam edge, well outside the region collimated with an applicator. The match to dose in the bremsstrahlung region was considerably better than previously published results for EGS4. **Conclusion:** This method gives more accurate estimates of source and geometry parameters than simulation of fields defined with an applicator. EGSnrc provides a better match than EGS4. This approach simplifies the commissioning procedure, relying on a single beam model, with parameters derived from a relatively small data set, to model all applicators. In addition, the beam has few energy-degraded, scattered electrons, relative to fields collimated with an applicator. A clean beam is much easier to model, opening up the possibility of achieving high accuracy in fluence estimation with a simple, experimentally-based beam model.

SU-FF-T-261

A Monte Carlo Model to Simulate Single and Double Strand Breaks in DNA Molecules

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Purpose: One of the most confounding issues in the treatment of cancer is that two patients with the same diagnosis respond differently to the same treatment. The ultimate goal of this research effort is to better understand why this occurs. As a first step, the study presented here is performed to develop a system of computer codes to model the complex reactions between ionizing radiation and DNA. **Method and Materials:** A mathematical atomistic model of a 167 base-pair B-DNA molecule was constructed using commercially available software packages. The probability of each possible fate of an •OH approaching to this 167 base-pair molecule was determined by implementing the "near-approach" DNA-radiation chemistry computational model described by Aydogan et al. (Radiat Res 157(1), 38-44, 2002) and compiled into an outcomes database. The secondary electron spectrum generated at depth in tissue by a Co-60 beam was modeled using the code MCNP 4.B. Two microdosimetry codes, OREC and RADLYS, originally developed at Oak Ridge National Laboratory, were adapted for this research. Attack sites were logged and single strand break (ssb) and double strand break (dsb) rates were calculated. **Results:** At a dose of 100 Gy, the concentration scaled dsb per molecule was only 0.4 which is in good agreement with the dsb data which is 0.43 dsb/ molecule from the computational effort described in this report. **Conclusion:** A Monte Carlo calculation model has been shown to simulate single and double strand breaks using a novel computational approach presented authors previously that reduces the computation time and eliminates unnecessary repetition of the computationally expensive near chemistry simulation in DNA damage. Experimental comparison of the single and double strand break yields calculated in this study have shown the accuracy of the DNA damage simulation model presented.

SU-FF-T-262

Advanced Irradiator for the Small Animal Conformal Treatment

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Purpose: Conformal irradiation of small animals represents an emerging research tool in the field of radiation oncology. Our institution is developing a treatment system for the small animal RT based on the ^{192}Ir radioactive source. Extensive Monte Carlo simulations were performed for the simple irradiator geometries with a single radioactive source and simple collimator apertures. In order to compensate for the severe inverse square law effects a series of simulations were performed involving 256 ^{192}Ir sources arranged in 16x16 planar matrix. **Method and Materials:** Simulations were performed using customized BEAMnrc code. The simulated geometry consisted of the source matrix positioned at the entrance of a meshed collimator. The collimator was a 2 cm thick tungsten slab with 256 (1x1 mm^2) square holes arranged to match the source matrix. The wall thickness between the adjacent holes was 1 mm. The final collimation element was a set of 2 cm thick tungsten leafs effectively enabling the choice of matrix elements included in the output beam. Dose distributions were scored in a 5x5x5 cm^3 water phantom with 1 mm^3 voxel-size. **Results:** The obtained dose distributions exhibit significantly less dose fall off vs. depth when compared to the single source geometry. The radial dose distribution and the size of the penumbra are comparable with the single source geometry but the angle of divergence is much smaller particularly for the higher irradiation field sizes. **Conclusion:** The novel design of the Ir192 irradiator has been tested via Monte Carlo simulations and exhibits significant improvements over simple geometries. Achievable depth dose curves and the small divergence of the beam promise much better conformal delivery. The design allows for IMRT-like treatment planning and is a strong candidate for an actual experimental realization.

SU-FF-T-263

Application of a Heterogeneous Coarse-Mesh Transport Method to a Radiation Therapy Benchmark Problem

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Purpose: To apply a new particle transport method that combines coarse-mesh transport and the Monte Carlo (MC) method to photons in radiation therapy to determine dose deposited and to quantify the increased speed and comparable accuracy of this method to the current pure MC methods. **Method and Materials:** A highly accurate and fast heterogeneous coarse-mesh transport method developed for neutrons in 2D geometry is extended to photon transport for radiation therapy. Its accuracy and speed for energy deposition estimation is shown in a benchmark phantom made of water. The phantom is modeled using a grid of coarse meshes to perform the transport calculation using a heterogeneous response function technique. MC calculations are used to precompute all of the material property dependent response functions that characterize the mesh. These functions that make up the data library are used in the deterministic transport calculation by sweeping through the grid to compute the angular partial currents at each coarse-mesh edge, and the energy deposited in the phantom.

To test the method, a comparison of the energy deposition in the benchmark phantom was performed by modeling the entire phantom directly with the MC code MCNP5. **Results:** The comparison over 150 meshes revealed an average relative error of the deposited energy of 2.25% between the two methods. However, the new method performed the calculation in 45 minutes, while MCNP5 required 2 hours. **Conclusion:** The work indicates that this new transport method has the potential to provide similar results as those obtained by using a pure MC method while reducing the amount of time required in obtaining these results. With further optimization of the heterogeneous coarse-mesh code, it is expected to further decrease the run time. The eventual 3D extension will allow calculating the actual dose deposited.

SU-FF-T-264

Clinical Impact of Seed Density and Prostate Elemental Composition On Permanent Seed Implant Dosimetry

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Purpose: To evaluated the impact of inter-seed attenuation and prostate elemental composition in clinical prostate treatment plans with 6711 125I permanent seed implants using the Monte Carlo (MC) method. The effect of seed density (number of seeds per prostate unit volume) is specifically investigated. **Method and Materials:** The MC toolkit Geant4 is used to perform the simulations. The study focuses on treatment plans that were generated for clinical cases. For each plan, four different dose calculation techniques are compared: TG43-based calculation, superposition MC (SMC), full MC with water prostate (MCW), and full MC with realistic prostate tissue (MCP). The SMC method is a technique for which a shifted one-source MC distribution is added to the total dose distribution for each source position. The realistic prostate composition includes the ten most abundant elements in prostate tissue based on ICRP23. **Results:** Seed density has a definite influence on inter-seed attenuation. A typical low seed density (42 0.6 mCi seeds in a 26 cc prostate) corresponds to a 0.7% drop in the CTV D90 value when comparing SMC to MCW while a drop of 2.5% is calculated for a higher seed density (75 0.3 mCi seeds, same prostate). The influence of the prostate elemental composition is similar for all plans. When comparing MCW to MCP, the difference in total dose deposited in the CTV is 3.0 +/- 0.2%, while it is 3.6 +/- 0.3% for the D90 parameter. When considering all effects, the variation on the CTV D90 value is ranging from 3.8% to 9.3% when comparing TG43 to MCP, depending on the seed density.

Conclusion: The MC study establishes the dependence of inter-seed attenuation on seed density and reveals a 3% overdose for a water prostate compared to a realistic composition. Overall, the effect on the CTV dosimetry is clinically significant.

SU-FF-T-265

Comparison of Absorbed Dose-To-Medium and Absorbed-Dose-To-Water for (head and Neck and Prostate) IMRT Treatment Plans

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Purpose: Conventional photon dose calculation algorithms typically report the absorbed dose-to-water(D_{water}). Monte Carlo(MC) dose calculation algorithms, however, by default reports the absorbed dose-to-medium(D_{medium}). It has been suggested that for clinical comparisons, MC-D_{medium} results should be converted into D_{water} to ensure valid comparisons. The goal of this study is to assess if the difference between D_{water} and D_{medium} is clinically significant for MC calculated IMRT plans. **Method and Materials:** Ten patients with H&N and ten patients with prostate cancer were selected for this study. Existing IMRT plans were re-calculated using an EGS4-based MC dose calculation system. D_{medium} was converted to D_{water} by multiplying D_{medium} results by average water-to-medium stopping power ratio. D_{water} and D_{medium} results for target and critical structures were evaluated using the DVH-based indices: D_2(dose to 2% of the structure volume), D_{50}(dose to 50% of the structure volume), D_{98}(dose to 98% of the target volume), and D_{mean}(mean dose). **Results:** For H&N, although the changes in average dose-volume indices were less than 1.5%, up to 6.2% differences in PTV_{CTV} D_2 were observed for individual patients. The cord and brainstem D_2 indices changed up to 2.5% and 2.7% respectively. For prostate, the differences in the indices for targets were less than 1%. The changes in critical structure indices were less than 1%, except for two patients in which changes up to 2.7% in rectum D_{50} index were observed. The increases in the range of 4.5- 11.5% in the femur dose-volume indices were observed in converting from D_{medium} to D_{water} due to the high calcium content of the hard bones. **Conclusion:** This study showed that converting dose-to-medium to dose-to-water in MC-based IMRT plans may significantly change the structure doses for some cases, especially when hard bone containing structures such as the femurs are present.

SU-FF-T-266

Comparison of the Measured Dose with the Dose Calculated with Superposition/convolution and Monte Carlo Algorithms From the Same Fluence Map for IMRT Fields

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Purpose: To compare the doses calculated for IMRT fields from the same fluence map with superposition/convolution and Monte Carlo algorithms and the measured dose. **Method and Materials:** A parallel version of the PENELOPE Monte Carlo (MC) code was utilized for particle transport inside the solid water phantom without and with inhomogeneity. The energy, location and direction of each particle entering the phantom was sampled from a fluence map generated by the commercial superposition/convolution (SC) algorithm for a commissioned accelerator. The 'pyramid' and small off-axis IMRT fields were studied. The doses calculated with MC code and SC from the same fluence map were benchmarked against doses obtained by HD-810 GafChromic® film for each setup. **Results:** For homogeneous setup the 'pyramid' field revealed close match between doses calculated by MC and SC, but the measurements at a depth of 10 cm showed some discrepancies in the penumbra regions. The presence of an airslab showed a discrepancy of up to 20 % between MC and SC dose values along the beam axis in the build-up region (up to 1.5 cm). The dose measured at 2 cm downstream from the airslab was different from the doses calculated with MC and SC. In the case of small fields all three doses: measured, and calculated with MC and SC were different. **Conclusion:** The agreement of doses measured and calculated with MC for the regions where the dose was not perturbed by inhomogeneities validated the fact that MC algorithm with initial parameters from the fluence map works properly. The difference among the doses calculated with SC and MC algorithms from the same fluence map and the measured dose is believed to be mainly due to the approximation of particles initial direction.

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SU-FF-T-267

Correlation of Electron Beam Parameters with Measured Dose Ratios in Clinical Photon Beams

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Purpose: The purpose of this work is to find a direct correlation between measured depth dose ratios and off axis ratios and two beam parameters for Monte Carlo simulations (i.e., the incident beam energy and radius) in clinical megavoltage photon beams in order to facilitate Monte Carlo applications in radiotherapy treatment planning. **Method and Materials:** The BEAM code was used to simulate the 6 MV photon beams from a Varian 2100C. A series of Monte Carlo simulations of Varian 2100C treatment head were performed for the incident beam energies from 5.1 MeV to 6.9 MeV and the beam radii from 0.03 cm to 0.12 cm. The calculated phase space files were then used for dose calculations in water. The depth dose ratio (DDR) defined as ratio of central axis depth dose at 20 cm to that at 10 cm and the off axis ratio (OAR) defined as ratio of dose at 10 cm in depth and 15 cm off axis to that at 10 cm on central axis as a function of incident electron beam energy and beam radius were studied. **Results:** For a fixed beam radius, the DDRs and OARs were linearly proportional to the incident beam energy for all the beam radii, with DDR = $0.5746 + 0.0072E_{in}$ and OAR = $1.4864 - 0.0824E_{in}$, respectively. However, for a fixed incident beam energy, both DDRs and OARs were found to be virtually independent of incident beam radius, which is inconsistent with

previously reported 18 MV photon beam in-air results (Med. Phys. 29, 379, 2002). **Conclusion:** The OARs are more sensitive than the DDRs to the incident beam energy. However, both ratios are essentially independent of incident beam radius.

SU-FF-T-268

Design Characteristics of a MLC for Proton Therapy

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Purpose: To determine the leaf design characteristics (separation between leaves, leaf width, step size, and divergent vs. non-divergent leaves) and the optimal distance-from-patient of a multileaf collimator (MLC) used in a proton therapy facility. These parameters have a significant effect on the penumbra width and leakage dose. **Method and Materials:** The GEANT4.7 Monte-Carlo code was used to simulate the various design parameters for the MLC. The geometry included a representative double-scattered beam incident on the MLC spaced at variable distances from a water phantom. Modifications were made to the code to input the leaf geometry from an external file so the many variations of leaf design could be tested without recompiling the code. **Results:** The output of the Monte-Carlo scored (1) the dose deposition in the water phantom, from which a measure of lateral penumbra as a function of depth and/or conformation to an pseudo-PTV could be determined, and (2) the number of secondary particles, e.g. neutrons, that were incident on the phantom and whether these secondary particles came through the MLC or in the gaps between the leaves. **Conclusion:** These results, along with mechanical-design, electrical-design, and cost considerations, are being used to design the proton therapy MLC to provide good dose conformation to the target while minimizing the normal tissue dose caused by leakage.

SU-FF-T-269

Dosimetric Properties of Scattered Photon Subsources Within a Source Model for Different Initial Electron Energies

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Purpose: Histogram-based Monte Carlo (MC) source models for dose calculations in radiotherapy require methods to scale input data so as to match measured accelerator output. A previous study showed that the photon beam characteristics remain constant when the radial intensity distribution of the initial electron beam varies, but changes for different mean initial electron energies $\overline{E}_e$. This work investigates the dosimetric properties of scattered photon subsources for different $\overline{E}_e$ striking the target and evaluates the scaling needed for those subsources to match dose distributions resulted for different $\overline{E}_e$. **Method and Materials:** Test scenarios were performed for 6-MV beams using $\overline{E}_e$=5, 6.2 and 7 MeV and for 18-MV beams using 17, 18, and 19 MeV. Histogram distributions for a previously developed MC source model were created based on phase–space data for these beams. 3D-dose distributions for a 10×10-cm^2 field at SSDs 50, 100 and 200-cm and a 30×30-cm^2 field at SSD 100-cm were calculated in water using different subsource combinations. The dose distributions are normalized to the same integral dose for the depth dose curve of the 10×10 cm^2 field at SSD 100 and compared based upon dose differences. **Results:** When scattered photon subsources associated with the 5-MeV simulation were used with the 7-MeV target subsource, <0.4% differences were found compared with using all the 7-MeV subsources in all cases studied. Differences were reduced to <0.2% when using the 6.2-MeV scattered subsources with the 7-MeV target subsource and were <0.2% when using either 17- or 18-MeV scatter subsources with the 19-MeV target subsource for 18-MV beams. **Conclusion:** These results suggest that apart from scaling the scattered subsource intensity, only the target subsource distributions need to be changed to adjust the histogram-based source model to dosimetrically match accelerator outputs due to $\overline{E}_e$ changes.

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SU-FF-T-270

Improving Simulation Efficiency of MLCs for Monte Carlo Based Dose Calculation of IMRT

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Purpose: Dose accuracy of Monte Carlo simulation (MCS) may critically depend on how MLCs are modeled for IMRT, however computation time increases significantly with the complexity of the MLC modeling. The purpose of this work are to determine (1) whether detailed modeling of complex leaf geometry is needed for clinical applications of MCS in IMRT; (2) whether simulation efficiency can be improved with simplified models of the MLC without sacrificing dose accuracy of MCS. **Method and Materials:**We studied leaf modeling for Varian 120-leaf MLCs with very sophisticated leaf design. The full MLC model used in MCS included rounded leaf end, and all details of tongue-groove design and leaf tips. In the simplified version, the rounded leaf end and leaf divergence were preserved; however, the leaves were approximated by rectangular regions with straight edges and no tongue-groove. The parameters for the simplified model (leaf density, leaf geometry, leaf gaps) were determined by measured transmission ratios and intensity maps. Intensity distributions and doses in water phantom and Rando phantoms for various testing leaf sequences and actual patient treatments were compared between the full and simplified leaf models. **Results:** It was possible to fine tune leaf geometry and air gaps in the simplified MLC model to match the measured transmission ratios. However with the simplified models, it was more challenging to match intensity maps with significant tongue-groove effects. Applying the simplified model along with appropriate variance reduction techniques (Ecut: from 0.7 to 5 MeV, Russian Roulette) could improve simulation efficiency by a factor of 17. The agreement between the full and simplified models for actual patient fields was clinically acceptable. **Conclusion:** Composite dose in patient fields delivered through multiple IMRT beams may not be sensitive to the detailed tongue-groove design of the MLCs. Varian reduction techniques are important for IMRT to improve simulation efficiency.

SU-FF-T-271

Influence of Initial Pencil Beam Parameters On Large Non-Applicator Electron Field Profiles Calculated Using Monte Carlo Methods

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Purpose: To investigate the influence of the initial pencil beam width on large non-applicator electron field profiles calculated using the BEAMnrc/EGSnrc Monte Carlo code. For a Varian 2100C linear accelerator, significant discrepancies of up to 10% in the shoulder of the profile were found between measured and calculated profiles for 40x40 cm^2 electron fields collimated using x-ray jaws alone, when using the standard electron spot size of 1.5 mm. A small angular variance of the electron pencil-beam at the x-ray target would be equivalent to increasing the electron pencil-beam spot size at the primary scattering foil, which would be expected to affect the electron fluence profile exiting the linear accelerator. **Method and Materials:** Cross-beam profiles at the depth of maximum central-axis dose were measured and calculated for electron beams with a field size of 40x40 cm^2 collimated by the x-ray jaws without an electron applicator. The electron spot size at the position of the x-ray target was modeled as a mono-energetic mono-directional Gaussian with a full-width half-maximum (FWHM) that varied from 1.5 to 5 mm. For each energy, measured and calculated profiles were compared to determine the optimal FWHM. **Results:** Adjusting the FWHM of the source greatly affected the shoulder of the calculated off-axis profiles, reducing discrepancies to ±4%. The optimal FWHM ranged 2.5 to 4.5 mm and was energy dependent. Assuming that the correct spot size at the x-ray target is 1.5 mm, this is equivalent to an angular spread at the x-ray target of 8.8 to 20.9 mrad. **Conclusion:** The angular spread of the electron pencil-beam at the x-ray target is significant and varies with energy, mostly influencing the shoulders of large non-applicator electron field profiles. The effect of the initial angular spread on other dosimetric data will be the subject of future investigations.

SU-FF-T-272

Low-Energy Photon Dose Calculations Using Various MCNP Photon Databases: Dose Comparison Between MCNP, PENELOPE, and EGSnrc

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Purpose: Recent releases of the MCNP5 and PENELOPE (2001) Monte Carlo codes use photo-atomic data from the most updated EPDL97 library, and include Doppler broadening in Compton scattering processes. Such advances in photon databases and transport algorithm are particularly important in low-energy photon dose calculations. **Method and Materials:** We computed radial dose distributions for r = 0.2–10 cm from a point source in a 50 cm-diameter sphere of water. Nine discrete energies for primary photon sources were chosen in the range of 10–150 keV. To isolate the effects of updated photoelectric data, Doppler broadening, bound electron model, and kerma approximation, we varied transport parameters and photon databases in the same simulation geometry using MCNP5 and MCNP4 with LIB04, LIB03, or LIB02 photon databases, PENELOPE, and EGSnrc. **Results:** The results from MCNP5/LIB04 agreed with those of PENELOPE within statistical uncertainties (±1%) over the entire ranges of energies and radial distances investigated. They also agree well with EGSnrc data within about ±2% (except for doses at 10 keV). MCNP/LIB02 or LIB03, on the other hand, produced doses up to 8% lower in the range of 20–80 keV than MCNP/LIB04 and PENELOPE. Such differences stem primarily from the differences in the photoelectric data used. The dosimetric effects of Doppler broadening and bound electron model for Compton interactions appear to be insignificant in the energy range investigated. Kerma calculated by photon only transport well approximates absorbed dose in water within statistical uncertainties (±1%) except for primary photons of E = 10 keV. **Conclusion:** Low-energy photon dose and kerma in water calculated by MCNP5 and MCNP4 with the updated photon database (LIB04) are comparable to doses by PENELOPE and EGSnrc.

SU-FF-T-273

Monte Carlo Calculation of Absorbed Dose to Structures in Central Nervous System From Intrathecally Administered Yttrium-90

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Intrathecal administration of I-131 labeled monoclonal antibody to CSF has been reported for the therapeutic treatment of CSF malignancies. Geometrical phantoms and MIRD formalism was used in the calculation of absorbed doses to neighboring structures. The purpose of this work is to calculate of the average absorbed dose to structures of the Central Nervous System from intrathecally administered Y-90 using digital phantom and Monte Carlo analysis. **Method and Materials:** Monte Carlo simulation of the energy deposition of Y-90 in anatomic model of ventricular spaces and spinal structures of the CNS tissue are used to calculate the dose to the Cerebral Spinal Fluid (CSF), meningeal structures of the spinal column and ventricular regions of the brain. Two three-dimensional phantoms, one for brain's ventricles and the other for 1.5 cm section of the spinal column were developed from MRI and visual woman images respectively. Voxel dimensions were in the order of (0.33 mm^3) for the study. A Monte Carlo energy deposition model for Y90 was used as point kernel and convolved with the model images to obtain final dose distribution. Calculation method was verified with I-131. **Results:** The average doses to the ventricular meninges, CSF and optic chiasm were calculated to be 2.4, 4.4 and 0.33 cGy/MBq of injected Y-90 respectively. For intrathecally administered I-131, the average dose for subarachnoid CSF and Pia mater were 1.31 and 0.34 cGy/MBq in this work while published results using the MIRD formalism reported values of 1.96 and 0.36 cGy/MBq respectively. Average doses to six spinal structures using administered Y-90 will also be presented. **Conclusion:** This work describes a useful technique for calculating absorbed dose and dose distribution to CSF and surrounding structures for the treatment of CSF malignancies by intrathecal injection. This approach can be used in similar therapeutic applications involving Y-90.

SU-FF-T-274

Monte Carlo Simulation of Radiation Induced Currents in Parallel Plate Ionization Chambers

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Purpose: To investigate the polarity effects caused by radiation induced currents, known also as Compton currents, in parallel plate ionization chambers. Compton currents arise as a result of charge imbalance due to charge deposition in electrodes during photon or electron beam irradiations. To allow for theoretical understanding of the effect, a modified user code COMPTON/EGSnrc was developed and used to study the effect in a phantom-embedded extrapolation chamber (PEEC). **Method and Materials:** The PEEC has a parallel-plate geometry with a variable electrode separation. The polarity effect of the PEEC was measured as a function of electrode separation, depth in phantom, and incident field size. Monte Carlo simulations using the COMPTON/EGSnrc user code were used to account for the charge entering into and exiting from the collecting electrode of the PEEC geometry, thereby yielding charge imbalance information. **Results:** The Compton current in the PEEC has a negligible dependence on electrode separation. In photon beams, the Compton currents with measurement depth exhibit a maximum at the surface and decrease with increasing depth to reach a minimum at the depth of dose maximum. The magnitude of the Compton current decreases with field size. In electron beams, the Compton current has a maximum positive value at the surface; decreases linearly with depth and becomes negative after a depth of about $0.2I_{50}$; then continues to decrease reaching a minimum at about $0.9I_{50}$; then increases rapidly to reach a zero value at R_P. **Conclusion:** Compton currents are the dominant cause of the polarity effect in parallel-plate ionization chambers and their variation with depth, field size, electrode separation in photon and electron beams can be determined with out modified user code COMPTON/EGSnrc.

SU-FF-T-275

Octree Based Compression Method of DICOM Images for Voxel Number Reduction and Faster Monte Carlo Simulations

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Purpose: Diminish the number of voxels created from a set of DICOM images. Keep critical information at tissue interfaces needed in a Monte Carlo simulation without compromising the physical quality of the voxelized image. **Method and Materials:** An algorithm was developed to apply an octree compression to DICOM images. The algorithm work as follow: the whole set of DICOM image is assumed as a cube. It is then split in eight equal smaller cubes. Each of the cubes is check for density homogeneity. . If a high density gradient is encountered in a cube, it is also split in height equal parts. This goes on until minimum voxel size is reach. The resulting image is composed of various voxels size. To test this approach, images from a CT calibration phantom which contains various densities were used. To verify precision, Monte Carlo simulation with GEANT4 using a narrow beam passing through several high density gradient was done.. **Results:** The resulting number of voxels range from 5 to 20% of the original size depending on configurations. The voxel area on a typical slice is 1 square voxel (i.e. no compression) at high density gradient to 64 square voxel for homogeneous sections. Mean volume was about 5.4^3 voxels for the phantom used. The octree has the particularity to smooth digital noise present in homogenous area. The density difference between the original and the octree images are directly related to this noise. Monte Carlo simulation shows less then 1% difference in dose at the high gradient interface. **Conclusion:** The octree compression is an excellent method to compress DICOM information for Monte Carlo treatment planning without losing precision at the interfaces in homogeneous regions. Given good parameters the algorithm also has the particularity to smooth digital noise in homogenous area.

SU-FF-T-276

SIRIT: An Electron-Gamma Shower Code with a New Structure

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Purpose: To investigate the feasibility of a new structure for Monte Carlo particle transport simulation codes that allows users to modify any aspect of the "physics" of the simulation without knowing any details about the code

system. Users can add their own code to simulate interactions or change the methods used to calculate condensed histories. A GUI is provided to run Monte Carlo simulations. From this GUI, users can also test/evaluate each interaction individually, and the calculation methods used to simulate condensed histories. **Method and Materials:** SPIRIT is being developed in Java on PCs running Linux and Windows operating systems. The Java platform was chosen because it offers platform independence, allows the code to be run both as an application and an applet, and is a powerful development environment, especially for GUIs and 1D/2D/3D/4D graphics. **Results:** SPIRIT is flexible and user-friendly, since it is an object oriented code system that does not use a preprocessor or macros, and does not require the user to know a "non-standard" language. Within a few hours, we expect new users will be able to use the program; add, remove, or replace interaction simulations; and test the influence of their modifications on the accuracy and speed of shower simulations. **Conclusion:** We have developed the first Monte Carlo transport code that allows users to change any part of the "physics" of the simulation by using a simple template, that requires no knowledge about the rest of the code system. Primary applications of SPIRIT, which is still being extended, include education and research related to Monte Carlo code development.

SU-FF-T-277

The Development and Implementation of a New Variance Reduction Technique in Monte Carlo Code PEREGRINE

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Purpose: The development and implementation of a new variance reduction technique (NVR) in Monte Carlo code PEREGRINE. **Method and Materials:** The NVR technique was designed to reduce computing time (to increase efficiency) of Monte Carlo (MC) simulations of therapeutic photon beams in arbitrary media. A simple case of monoenergetic photon beam in water phantom is sufficient to describe the idea of NVR. As the primary photon fluence attenuates exponentially with phantom depth z, statistical uncertainty of absorbed dose increases with z as $(N_z)^{-1/2}$, where $N_z=N_0 \cdot \exp(-\mu z)$ is the number of histories available at depth z, N_0 is the number of initial histories and μ is the linear attenuation coefficient for primary radiation in water. If at a depth of interest d, N_d yields an acceptable dose uncertainty, then instead of N_0 initial histories, one can use only N_d histories if this number is maintained invariant with phantom depth. This can be done by "recovering" each interacted primary photon back to the primary fluence, thus making it available for further interactions. In doing so, all offspring particles should be given a dose weight factor $\exp(-\mu z)$ corresponding to the depth z of the primary photon interaction. Because $N_d << N_0$, computing time is significantly reduced. **Results:** Implemented in PEREGRINE, NVR increases computational efficiency without biasing the dose distributions in various heterogeneous phantoms. In the case of a patient-specific CT-based anatomy, NVR reduces the computing time by a factor of ~2, and in metals (blocks, wedges, MLCs) by a factor of 10 or more. **Conclusion:** NVR is an unbiased technique compatible with other variance reduction techniques. Therefore, it can be combined with such techniques to further increase efficiency of MC codes. NVR results in an enhancement of MC efficiency that is clinically significant. **Conflict of Interest:** This research was supported by NIH grant 1R41CA108088.

SU-FF-T-278

The Dose Discrepancies Between Monte Carlo Calculations and Measurements in the Build-Up Region for High-Energy Photon Beams

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Purpose: To study the dose discrepancies between Monte Carlo calculations and measurements in the build-up region for high energy photon beams. There are previous studies which show that neutrons present in a high-energy photon beam are unlikely to be responsible for the reported discrepancies (Ding *et al* 2002, Hartmann Siantar *et al* 2001) in the build-up region for large fields. It is necessary to figure out if the discrepancy could be a result of flaws in the Monte Carlo simulation or uncertainties in the measured data in the build-up region. **Method and Materials:** The EGSnrc Monte Carlo code, BEAMnrc, has been used to simulate dose distributions produced by 23MV photon beams from a Siemens Primus Linac for 5x5cm^2, 10x10 cm^2, 15x15 cm^2, 25x25 cm^2 and 40x40 cm^2 field sizes. The simulation of the accelerator was accomplished in two stages. The stored phase space file from the first stage was used repeatedly for the second stage as source data. The corresponding depth-dose curves in the build-up region for the above field sizes were measured in the solid water by a plane parallel chamber and in water by a cylindrical chamber. **Results:** Comparisons between the calculations and measurements reveal the dose discrepancies in the build-up region fields increase with increasing field size. However, the differences between the measurements by different measurement detectors are far less than those between the calculations and measurements. **Conclusion:** The discrepancy is caused by the simulation itself. Just as Hartmann Siantar C L *et al* (2001) hypothesized, it may be caused by a source of electrons in the accelerator head that was not fully accounted for in the treatment head simulation.

SU-FF-T-279

The Validation of a Highly Detailed Multi Leaf Collimator Model by Comparing Monte Carlo Simulations to Measurements

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Purpose: The validation of a highly detailed multi leaf collimator model by comparing Monte Carlo simulations to measurements. **Method and Materials:** The MCNPX Monte Carlo model of the treatment head consists of bremsstrahlung target, collimators, flattening filter, jaws, a variable multi leaf collimator, and shielding as well as structural support material. A set of dosimetric measurements (lateral profiles, depth dose curves, multi leaf collimator transmission, tongue and grove test) with 6-MV and 18-MV photon beams have been performed on a Varian Clinac 2100EX. The measured data were compared to Monte Carlo simulations. **Results:** The measured and simulated depth dose profiles are in very good agreement for both photon energies distal to the maximum dose. The average deviation is less than 1.1%. The simulated cross-plane and in-plane profiles are in excellent agreement with measurements (deviation 0.5% for 6-MV and 1.1% for 18-MV within the 80% plateau region). The measured photon transmission of a completely closed multi leaf collimator has a value of 1.72%±0.05% and 1.93%±0.05% for 6-MV and 18-MV respectively. The simulated transmission depends on the size of the inter-leaf air gap and the electron transport cutoff energy. Using an air gap of 0.047 mm and a cutoff value of 0.1 MeV results in a transmission of 1.78%±0.05% and 1.95%±0.05% for 6-MV and 18-MV. The tongue and grove test shows an excellent agreement of measurement and simulation. **Conclusion:** An extremely detailed model of a Millennium 120 multi leaf collimator has been constructed and simulations using this model were compared successfully to measurements. All results indicate that the model is valid and accurate. Complete IMRT treatments can now be simulated and the peripheral photon and neutron dose can be investigated.

SU-FF-T-280

Verification of Monte Carlo Simulations of Proton Dose Distributions in Biological Media

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Purpose: Aim of this work is to suggest a method for verifying the ability of Monte Carlo codes at simulating proton transport through biological tissues defined by CT Hounsfield units. **Method and Materials:** The method is based on the assumption that the main physical processes leading to proton energy deposition are Coulomb interactions. It consists first in simulating the two- or three-dimensional dose distributions from a monoenergetic proton pencil beam impinging in various homogeneous phantoms filled with water and with biological tissue. The indicators for the Coulomb interactions are extracted from the dose distributions: these are the proton stopping powers relative to water and the lateral scaling factors, which characterize respectively the longitudinal loss of energy and the scattering properties in the material traversed. Third, these values extracted from the Monte Carlo simulations are compared to the expected analytical values of the stopping powers and of the lateral scaling factors for various proton energies in water and in several biological materials. **Results:** This method was applied to two versions of the Monte Carlo code GEANT4. Results show that while the values for the stopping powers extracted from

the simulations are in good agreement with the analytical or tabulated values, non negligible discrepancies in the simulation of proton scattering exist between the former version of GEANT4 and the analytical predictions: in the former version about 16.0% deviations were found in the simulation of the proton beam broadening in water and in material. The best agreement with the analytical values for the Coulomb indicators (less than 3.0%) was provided by the current latest version GEANT4.7.0 **Conclusion:** The evaluation of GEANT4 using this validation method for Coulomb interactions shows that GEANT4 can be used as a benchmarking tool for proton dose calculations on CT data. **Conflict of Interest:** Research supported by Siemens OCS

SU-FF-T-281

Accuracy of a Commercial Macro Monte Carlo Dose Calculation Algorithm for Determination of In-Water Output Factors of Clinical Electron Field Shapes

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Purpose: To evaluate the accuracy of a commercial implementation of the macro Monte Carlo method for determination of in-water output factors of clinical electron field shapes. **Method and Materials:** At our institution, we calculate electron monitor unit settings by measuring the output relative to the calibration condition. For each measurement, the measurement conditions (machine, energy, SSD, and applicator size), the field outline, and the output factor are recorded and maintained in a library. We obtained the output factors for 190 field shapes from our library for three dosimetrically equivalent linear accelerators. Because there were relatively few fields at the largest applicator size and at the two highest energies, 15 and 18 MeV, we selected and measured additional field shapes for each energy/applicator combination that had fewer than four field shapes, resulting in a total of 218 field shapes. Output factors were calculated by digitizing the field shapes into the treatment planning system and calculating the dose at the measurement point using a synthetic CT data set of a flat water phantom. The algorithm parameters were maximum calculation accuracy (1%), calculation grid size such that there were approximately 10 calculation points in the distal falloff of the central axis depth dose, and for no smoothing of the dose distribution. Output factors were remeasured for field shapes for which the disagreement was larger than 2%. **Results:** The mean difference between the calculation and measurement was -0.2%, and the standard deviation of the difference distribution was 1.1%. Of the 218 measurements, 124 (56.9%), 211 (96.8%), and 215 (98.6%) were within 1%, 2%, and 3%, respectively. The largest difference was 3.4%. **Conclusion:** Our evaluation demonstrated that the algorithm performs well for determination of in-water output factors for clinical field shapes. The majority of calculated output factors were within 2% of measurement.

SU-FF-T-282

Beam Modifier Design for Total Skin Electron Irradiations Using Monte Carlo Techniques

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Purpose: Total skin electron irradiation (TSEI) requires large electron beams having good dose uniformity, d_{max} at the skin surface, and low bremsstrahlung contamination. Energy degraders and scattering foils have to be specially designed for the given accelerator and treatment room. **Method and Materials:** Monte Carlo (MC) techniques based on EGS4 user codes (BEAM, DOSXYZ, and DOSRZ) guided the beam modifier design of our TSEI system. The dosimetric characteristics at the treatment distance of 382 cm SSD were verified experimentally using a linear array of 47 ion-chambers, a parallel plate chamber, and radiochromic film. By matching MC simulations to standard beam measurements at 100 cm SSD, the parameters of primary electrons were determined to be mono-energetic at 6.72 MeV, parallel, and circular beams having a Gaussian radial distribution with FWHM = 0.13 cm. They were then used to simulate our TSEI with eight sets of energy degraders and flattening filters. **Results:** An energy degrader of a 0.6 cm-thick PMMA plate, blacking a jaw-shaped field (40×40 cm^2) at 100 cm SSD, showed the best performance in terms of dose rate and uniformity. A flattening filter, consisting of a 12×12 cm^2 aluminum plate of 0.6 cm-thickness and placed just behind the energy degrader was considered optimal. Such optimized combination produced a beam that was flat within ±3% up to 60 cm off-axis distance, dropped by not more than 6% at a distance of 90 cm, and had an x-ray of < 3%. The maximum dose of the rotating phantom occurred at the surface and was approximately 40% of the maximum dose (at 0.65 cm-depth) of the stationary phantom. **Conclusion:** By evaluating the dosimetric performance of beam modifier designs for TSEI, the Monte Carlo simulations reduced the costly efforts that could, otherwise, result from constructing and measuring lots of prototypes.

SU-FF-T-283

Benchmarking of An Event-By-Event Monte Carlo Code, NOREC: Generation of Scaled Point Kernels in Water for Mono-Energetic Electrons Between 10 KeV and 1 MeV

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Purpose: To compare scaled point kernels (SPK) in water for mono-energetic electrons generated by an event-by-event Monte Carlo code, NOREC, with published kernels based on a condensed history Monte Carlo code. **Method and Materials:** An event-by-event Monte Carlo code called NOREC, which replaces the Oak Ridge electron transport code (OREC), was released in 2003, after a number of modifications to the OREC including the replacement of the original OREC elastic cross sections by a newer data set from the National Institute of Standards and Technology (NIST). Initial benchmark tests showed that, for a number of dosimetric quantities (e.g., electron depth dose distribution), NOREC was capable of producing better agreement with published results than OREC, which indicates the effectiveness of the modifications introduced to the code. For a more comprehensive benchmarking, NOREC was used in this study to generate scaled point kernels for a number of electron energies between 0.01 and 1.0 MeV. Calculated kernels were compared with published kernels (i.e., the so-called Berger kernels) based on a condensed history Monte Carlo code, ETRAN. **Results:** Although qualitatively similar, scaled point kernels generated by NOREC generally showed more energy deposition in the first half of continuous slowing down approximation (CSDA) electron ranges than the Berger kernels. Calculated ranges of electrons were similar between the two kernels. **Conclusion:** NOREC can produce SPK comparable to those generated by ETRAN. The current results suggest that NOREC can be used for both micro- and macro-dosimetry problems which require more detailed transport of electrons below 1 MeV.

SU-FF-T-284

Characterising An Electron Pencil Beam: Monte Carlo Vs Measurement

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Purpose: Electron beams from linear accelerators have widely varying characteristics in terms of spectral properties, mixtures of electrons and photons, spatial and angular characteristics. Characterizing pencil beams for pencil-beam based calculations and for complex electron optimization calculations is thus necessary for individual electron beams. We evaluated an extrapolation method for characterizing an electron pencil beam and compared a Monte Carlo based method with measurement. **Method and Materials:** Radiographic film was used to measure narrow 12 MeV electron beams from a Varian 21EX accelerator. A series of circular beams was considered, collimated with LMPA material between diameters of 1.5 and 32 millimeters. Beam profiles were measured at discrete depths, and the presence of photon contamination from the LMPA was accounted for by subtracting measurements for a solid piece of LMPA. From these measurements, an extrapolation was made to estimate the distribution for a 0.1 mm diameter beam. A similar process was carried out using EGSnrc Monte Carlo, with electron beam characteristics determined using BEAM. **Results:** A large amount of similarity was found between pencil beam distributions extrapolated from film-measured and Monte Carlo derived data. Given the amount of noise present in the measured and simulated results, the curve-fitting procedure yielded relatively smooth and appropriate pencil beam distributions. It was also found that the parameters from the curve-fitting could be used to extract central axis percentage depth dose distributions which were consistent (past d_{max}) with measured broad beam data. **Conclusion:** This study showed that the extrapolation method is appropriate for derivation of dose distributions for very narrow beams. A Monte Carlo simulated narrow beam distribution would normally be

sufficient for characterizing such a distribution, though if high resolution is required, the extrapolation method would be useful.

SU-FF-T-285

Dose Property of Grid Therapy

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The possibility of a therapeutic advantage in the use of a megavoltage grid to deliver large single dose fractions has been previously demonstrated. Assessment of dose response characteristics is essential to the understanding and use of grid therapy in the clinic. A Wellhofer scanning system, an EDR2 film dose measurement device, and Monte Carlo calculations were used in evaluating the dosimetric properties of a megavoltage grid. A range of grid hole diameters was simulated by the Monte Carlo technique, and a 0.8 cm diameter grid was singled out to carry out a comprehensive comparison between the measurements and Monte Carlo calculations. The maximum and minimum doses, and dose profiles at the depth of maximum dose d_{max} as well as the percentage depth dose were obtained. With the dose normalized at 100 cGy at d_{max} in a 10x10 cm^2 open field, the maximum dose for the grid was found to range from 11.9 to 94.5 cGy when the diameter of grid was varied from 0.2 to 1.0 cm, while the minimum dose between holes increased only from 6.8 to 16.1 cGy. A fairly good agreement between the Monte Carlo simulated and measured data was demonstrated for the 0.8 cm diameter grid. With our calculated results, the cell survival rates for grid therapy were further derived using a linear-quadratic survival model, and a therapeutic advantage for the grid was confirmed for large single fractions.

SU-FF-T-286

Dosimetric Evaluation of the PEREGRINE IMRT MC Treatment Planning System at 6 MV for Small Fields in Heterogeneous Media

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Purpose: In a previous study Heath et al. reported good dosimetric accuracy between PEREGRINE and measurements in homogeneous and heterogeneous media, for 1x1 to 30x30 cm^2 fields. However, dosimetric accuracy for large field horns and inside the lung-equivalent phantom remained subject to further investigation. This work compares the effect of parameters directly related to the phantom with those related to linac beam modeling and discusses their effect on the calculated dose inside the heterogeneity. **Method and Materials:** To investigate the factors influencing the accuracy of 1x1 cm^2 depth dose profiles in lung, several dose calculations were performed and the effect of the following parameters were studied: the mathematical phantom's resolution, slice thickness, composition, density and dose collection voxel shape and size; and parameters influencing the PEREGRINE device file (which is the MC-derived correlated-histograms model of the beam) such as the width and shape of the electron beam (incident on the linac target) intensity distribution. **Results:** Our results show that modeling the lung component of the phantom as GAMMEX-RMI lung-equivalent material (ρ = 0.271 g/ cm^3) or as lung tissue (ρ = 0.26 g/ cm^3) results in less than 1% difference in dose to the lung, whereas using a device file with an optimized electron beam set of parameters to match the large field off-axis dose profiles results in 3% dose to lung difference. The agreement in dose to lung between this version of the device file and corresponding EGSnrc calculations is within 1%. **Conclusion:** When performing dosimetric verification calculations in heterogeneous media especially for small fields, attention must be paid to the effect of the details of the linac beam MC model (particularly the electron beam parameters) on the calculated dose in heterogeneities. **Conflict of Interest:** This work is supported by North American Scientific (Nomos Radiation Oncology Division).

SU-FF-T-287

Effect of Tissue Inhomogeneitis On MU Required to Deliver Prescribed Dose - Monte Carlo Study

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Purpose: The purpose of this study is to evaluate the effect of tissue inhomogeneities and surface irregularities on the value of monitor units, MU, calculated for radiotherapy treatments with electron beams of various anatomical sites. **Method and Materials:** The Monte Carlo software used is the commercial implementation of VMC++ (Nucletron). For each CT based patient anatomy three types of calculations are performed: with inhomogeneity and surface corrections, with surface correction only (no inhomogeneity correction), and water tank geometry (no inhomogeneity or surface corrections). The Monte Carlo software was set to calculate dose to medium. The 0.49 cm^3 calculation voxels had an overall statistical uncertainty of about 1.5%. **Results:** Dose distributions for 20 breast and 20 head and neck patients were analyzed. The electron beam energy was chosen so that the treatment target was encompassed by the 90% isodose when both inhomogeneity and surface corrections were applied. The dose prescription point was typically selected on the 90% isodose or at d_{max}. For breast cases MU calculated with both corrections differed by up to 7% compared to the water tank geometry. When the target was close to the lung more MU were needed to deliver the prescribed dose when inhomogeneity correction was included. This is due to the decrease in scatter contribution from the lung to the target volume. In head and neck, the largest observed difference between the Monte Carlo based MU on the true patient anatomy and water tank reached 15% for the anterior nose treatment. **Conclusion:** Prescribing electron treatments using MUs based on patient anatomy leads to delivery of the true prescribed dose. Prescriptions based on water tank geometry may lead to under-dosing of up to 15%. Retrospective and prospective studies are needed to evaluate the impact of MUs based on real patient anatomy on treatment outcomes.

SU-FF-T-288

Evaluation of a Commercial Macro Monte Carlo Electron Dose Calculation Algorithm

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Purpose: To evaluate electron dose distributions calculated by a recently released commercial implementation of the macro Monte Carlo method for complex geometries and in the presence of heterogeneities. **Method and Materials:** A set of two-dimensional dose distributions, published for the purpose of evaluating electron dose calculation algorithms, was obtained. The data are comprised of measurements for two energies, 9 MeV and 20 MeV, and five phantom geometries, which, in combination, resulted in fourteen measurement configurations. The data set did not contain sufficient information for the configuration of the algorithm, so measurements of the necessary data were obtained from a dosimetrically equivalent machine. A virtual machine was created in the treatment planning system to model the linear accelerator used to acquire the data set. Synthetic CT data sets and RT structure sets modeling the phantom configurations were created and calculations were performed using a range of algorithm parameter values (accuracy, smoothing, and grid spacing) for all fourteen configurations. The transverse plane containing the central axis was extracted for comparison with the measured distributions and dose difference and distance-to-agreement were calculated. **Results:** More than 99.5% of the calculation points were within 3% difference and 3 mm distance-to-agreement for the best set of parameters. The number of points violating the criteria increased with decreasing accuracy. Without smoothing of the dose distribution, points violating the criteria tended to be located throughout the calculation volume. With the addition of smoothing, the number of points increased and became clustered in regions of high dose gradient. **Conclusion:** Our evaluation demonstrated that the algorithm performs well in complex geometries in the presence of heterogeneities. In general, agreement was better than 3% and 3 mm. We have investigated the influence of the algorithm parameters on the agreement, which will allow users to make appropriate choices for clinical calculations.

SU-FF-T-289

Healing Well: A New Concept for Radiation Therapy of Breast Cancer

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Purpose: To propose a new concept/device, termed Healing Well, dedicating to radiotherapy of breast cancer. This objective is motivated by the need to reduce overall treatment time and to reduce toxicity observed on patients with large breasts. **Methods and Material:** The basic idea of Heal Well is to use a cup-shaped structure (well) with tens of collimated channels similar to the Gamma-Knife. Unlike the Gamma-knife, the source is provided through a HDR ^{60}Co afterloader and the beams are not narrowly focused to a small spot. The device delivers low-dose-rate radiation with patient in the prone position and the breast placed inside the well by gravity. The EGSnrc Monte-Carlo system was used to explore sample design and to compute dose distributions. A commercial ^{60}Co DHR source (Shimadzu Corp.) situated in the housing and collimating structure of the Healing Well was modeled with Monte-Carlo. Dose distribution for a hypothetical ^{60}Co ring source was calculated, and was compared with those of a 6MV and a 15MV parallel-opposite pairs commonly used. **Results:** The Monte-Carlo calculation for the ^{60}Co HDR source showed that a dose rate of approximate 2 cGy/min was produced at a distance of 15 cm. This dose rate may be too low, thus, source strength should be increased. The calculation for the ring source shows that the ^{60}Co is as penetrating as the 15 MV beam and produces even more uniform dose distribution than the 6 and 15 MV pairs, indicating that the ^{60}Co in the Healing Well configuration has sufficient penetration for large breasts. **Conclusion:** This work propose a new concept/device that is dedicated to treat breast cancer by irradiating the breast inside a well. The technology has a potential to improve cosmetic outcome and/or quality of life for breast cancer patients, particularly for those with large, pendulous, breasts.

SU-FF-T-290

Impact of MLC Modeling and Sensitivity of Its Parameters On Monte Carlo Simulation of IMRT

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Purpose: Monte Carlo simulation (MCS) offers the most sophisticated dose calculation for IMRT with complex delivery systems using MLCs. The purposes of this work are to determine: (1) to what degree of accuracy and complexity MLCs have to be modeled in MCS; (2) what are the most sensitive tests and effective ways of determining free parameters for MCS-IMRT, including leaf density, leaf geometry, and incident electron beam source size. **Method and Materials:** A generic MLC model was developed for BEAMnrc system. This model described MLCs based on matrices of regions, each of which can be independently defined for its material and geometry, allowing maximum flexibility of simulating MLCs for various manufacturers. To commission the MLC model for Varian Millenium MLC, we measured transmission ratios and intensity maps for various leaf patterns designed to magnify the effects of leaf transmission, leakage, and tongue-and-groove. In addition, TLD measurements were also taken for clinical IMRT plans using anthropomorphic phantoms. Several parameter sets of leaf density, leaf geometry, and electron source size were tested to evaluate dosimetric effects of these parameters and to determine the optimal combination. **Results:** The overall-transmission ratios were strongly dependent on both leaf density and inter-leaf air gap. Meanwhile, electron source size had less effect on transmission and leakage. Inter-leaf air gap and tongue-and-groove geometry can be determined most effectively through fence-type MLC patterns. The optimal parameter range was 17.35-17.70g/cm^3 for leaf density, 0.08–0.11mm for inter-leaf air gap with detailed tongue-and-groove modeling, and 0.1-0.2cm for electron source size. With these parameters, MCS calculated and measured TLD dose showed clinical-acceptable agreement from low to high dose regions. **Conclusion:** MLC modeling critically affected the accuracy of MCS for IMRT. The free parameters for the MLC have to be carefully determined by separate measurements for MCS.

SU-FF-T-291

Monte Carlo Calculation of Rectal Dose When Using An Endorectal Balloon During Prostate Radiation Therapy

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Purpose: Air-filled intrarectal balloons can be used to localize and immobilize the prostate for radiation therapy. This project investigates how well the Eclipse treatment planning system (Varian Inc.) includes the effect of this potentially significant heterogeneity on doses to the rectum. **Method and Materials:** The BEAMnrc/DOSXYZnrc Monte Carlo (MC) codes were used to simulate a 4-field conformal therapy treatment for patients who have been treated for prostate cancer under an IRB-approved protocol which includes a 27Gy cone-down using a rectal balloon. The rectal doses calculated using MC were compared with those from Eclipse using isodose curves, dose-volume histograms, and wall-volume histograms. **Results:** The MC results showed that, for a 27Gy prescription to the 95% isodose line, Eclipse over-estimates the volume of the rectum receiving more than 26 Gy by 2-10cc and the volume of the rectum receiving between 12-15 Gy by 10-20cc. **Conclusion:** The differences in the rectal dose calculated by Eclipse and MC are consistent and can be predicted. They can be explained by the scattering behavior of the PA and lateral fields inside the balloon: For each field, the lack of electronic equilibrium reduces the high dose region while the increased electron range widens the low dose region beyond the penumbra. The combined effect of the four fields divides the DVH into two major regions, corresponding to the AP-PA and lateral fields, and four subregions, corresponding to the scattering behavior of electrons in air.

SU-FF-T-292

Monte Carlo Evaluation of Cerrobend Eye Shield in Electron Beam Treatment

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Purpose: The purpose of this study was to evaluate and validate the shielding effect of a cerrobend eye shield using Monte Carlo simulation. **Method and Materials:** A customized cerrobend cylindrical eye shield was made and attached to a hemisphere plastic sheath to protect the lens during orbital lymphoma treatment with a 12 MeV electron beam from a Varian 2100C Linac. Film dosimetry was accomplished for open and shielded beams at 10x10 cm^2 field size using a 30x30x30 cm^3 solid water phantom. Monte Carlo simulation based on EGSnrc/DOSRZnrc code was performed to obtain the open and the shielded dose distributions. Comparisons between the film measurements and the simulations are presented. The dose distribution of a shielded eye with 1 cm bolus is calculated by both Philips Pinnacle treatment planning system and Monte Carlo simulation with the same geometric considerations. The two results were compared. **Results:** For the open field, the agreement between Monte Carlo simulation and film measurement was within 1%/1 mm for both percentage depth dose curves and cross beam profiles. For the shielded field, the agreement between simulation and film measurement was within 3%/2 mm for percentage depth dose curves and 2%/1mm for cross beam profiles. The treatment planning system could not provide reasonable results because of the high density of cerrobend. The simulation assured us that the dose to the lens is less than 10% of the tumor dose. **Conclusion:** For the dose distribution evaluation of orbital lymphoma treatments with shielding, film measurements and treatment planning system have limitations due to non-regular geometry and inadequate inhomogeneity correction for high Z materials. Monte Carlo simulations provide assurance of dose distribution to physicians with acceptable accuracy.

SU-FF-T-293

Monte Carlo Modeling of the Xoft AXXENTTM X-Ray Source

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Purpose: Extensive Monte Carlo modeling was performed using MCNP5 to characterize the Xoft AXXENT™ miniature x-ray source for electronic brachytherapy. This study assessed the dose distribution, dosimetry parameters using the AAPM TG-43U1 protocol, and the sensitivity of results to source geometric parameters and choices of computational parameters. **Method and Materials:** Monte Carlo simulations of radiation generation and transport utilized the MCNP5 code and EPDL97-based mcplib04 cross-section library. Dosimetry parameters using a modified TG-43U1 2-D dosimetry formalism were determined at 40, 45, and 50 kV operating voltages. While the source was modeled as a point due to small

anode size, < 1 mm, the 1-D brachytherapy dosimetry formalism is not appropriate due to significant polar anisotropy. Source output was measured in a water phantom using a PTW 34013 Ion Chamber. **Results:** Calculated point-source model radial dose functions at $g_P(5)$ were 0.19, 0.24, and 0.29 for the 40, 45, and 50 kV voltage settings, respectively. Measured point-source model radial dose functions were ± 10% of the calculated results for 1.5 cm ≤ r ≤ 7.0 cm. Calculated F(r,θ) values for all operating voltages were typically 1.1 along the distal end (θ = 0°) and ranged from F(0.5, 160°) = 0.2 to F(10, 160°) = 0.5 near the catheter proximal end. Default energy substep values, *estep*, for photon generation in the anode film and substrate were found to be adequate. Doubling the default values effected the number of x-rays and brehmsstrahlung photons generated by <1%. Utilizing geometry splitting/rouletting and brehmsstrahlung biasing for variance reduction improved the computational efficiency by >30x. **Conclusion:** A miniature x-ray source for electronic brachytherapy has been characterized using MCNP5. The Monte Carlo results agreed with measured results for radial dose function and anisotropy function to within ± 10%. **Conflict of Interest:** Research was supported by Xoft, Inc.

SU-FF-T-294

Monte Carlo Simulations of the Dosimetric Characteristics of a New Multileaf Collimator

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Purpose: The aim of the work was to investigate the dosimetric characteristics of a new multileaf collimator (160MLC™, Siemens) with the help of Monte Carlo (MC) simulations during the design phase. **Method and Materials:** The MLC was implemented in the MC code Geant4. For the simulation of the 6 MV treatment beam an experimentally validated phase space and a virtual source model were used. For the simulation of the geometry in Geant4 the jaws and the two leaf packages were implemented with the help of CAD data. First, transmission values for different tungsten sinters were extracted using the simulation codes Geant4 and BEAMnrc and compared to experimental measurements. In a second step, high resolution simulations were performed to detect the leakage at depth of maximum dose. The 20%-80% penumbra along the leaf travel direction was determined for different 10x10 cm² fields shifted along the x-axis. The simulated results were compared with measured data obtained with a prototype. **Results:** The simulation of the transmission values for different tungsten sinters showed a good agreement with the experimental measurements (within 2.0%). This gave an accurate estimation of the absorption coefficient for various leaf materials. Simulations with varying source sizes showed that the leakage and the penumbra depended very much on this parameter: e.g. source sizes of 2 mm and 4 mm result in the interleaf leakages below 0.3% and 0.75% respectively. The results for the leakage and the penumbra are in good agreement with the measurements. **Conclusion:** This study showed that Geant4 is appropriate for the investigation of the dosimetric characteristics of a multileaf collimator. In particular we could quantify the leakage and the penumbra and evaluate the influence of the beam parameters such as the virtual source size. **Conflict of Interest:** Research supported by Siemens Oncology Care Systems.

SU-FF-T-295

Monte Carlo Treatment Planning: The Influence of "variance Reduction" Techniques (ECUT, PCUT, ESTEP) On the Accuracy and Speed of Dose Calculations

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Purpose: To investigate the influence of low energy electron cutoff values and electron step size on accuracy and speed of dose calculations in MC treatment planning over a range of anatomical sites. Because low energy cutoffs and electron step size are not true variance reduction techniques, they are likely (if not used judiciously) to systematically bias the results. Consequently, tradeoffs between accuracy and speed associated with the use of these parameters must be carefully examined over the range of sites encountered in MC clinical planning. **Method and Materials:** MC planning (using RT_DPM) was performed for several anatomical sites including the head/neck, lung and prostate. Plans generally consisted of complex, multiple segment fields using 6 and/or 15 MV photons. Multiple calculations were performed for each treatment plan in which each of the parameters, ECUT, PCUT, and ESTEP were independently varied. ECUT ranged from 10 to 500 keV for two values of PCUT, 10 and 50 keV – typical values encountered in clinical MC planning. ESTEP ranged from 2 to 5 mm. Additionally, the scoring voxel size was reduced from 5 to 2.5 mm^3 in some cases. All calculations were performed with sufficient histories for average uncertainties (1σ) of less than 1% within the PTV's. **Results:** Evaluation a variety of dose metrics showed in some instances significant differences amongst plans using different cutoff and step values. We demonstrate that for treatment sites, such as the lung and head/neck, where low density structures are prevalent, even the use of conservative cutoffs (ECUT=50 keV) introduce significant systematic errors. In contrast, for homogeneous (water-like) sites, such as the prostate, the time savings associated with use of higher energy cutoffs may be taken advantage of without affecting the dose accuracy. **Conclusion:** Further studies of energy cutoffs and step sizes are warranted before MC is used for routine clinical planning.

SU-FF-T-296

Parameterizing the Phantom Scatter Components for Polyenergetic Photon Beams

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Purpose: To develop an improved analytical model of the phantom scatter-to-primary ratio *(SPR)* of megavoltage photon beams with improved accuracy for a wider range of field sizes and depths than the existing analytical model [1] by accounting for backscattered photons. **Method and Materials:** EGS4 Monte-Carlo simulations are performed to calculate the scatter and primary doses from parallel photon beams for ^{60}Co spectrum and the Mohan spectra simulating photon beams with nominal energies of 4, 6, 10, 15, and 24 MV. The depths varied from d_{max} to 30 cm. The field size varied between 3 and 40 cm. SPR has previously been modeled by the equation $SPR=(a_0\ s\ d)/(w_0\ s + d)$ [1]. We model *SPR* by $SPR=(a_0\ s\ (d+d_0))/(w_0\ s + (d+d_0))$, where s is the field size at depth, *d* is the depth in the phantom, and a_0, w_0 and d_0 are free parameters. The addition of the depth offset d_0 accounts for the dependence of *SPR* on field size at shallow depths. We fit the *SPR* data derived from Monte Carlo simulation to determine a_0, w_0 and d_0 for each of the simulated nominal energies. **Results:** The phantom scatter-to-primary ratio increases with increasing depth and field size, up to 161% and 34% for ^{60}Co and 24 MV, respectively, for s = 40 cm and d = 30 cm. The maximum (standard) error for the new and standard analytical models are 3.5% (1.1%) and 2.2 % (1.1%), respectively, for 6 MV. At shallow depths (d_{max}), the maximum (standard) error of the fitting are 6.4% (3.9%) and 4.2 % (2.4%), respectively, for ^{60}Co, and decreases with increasing nominal energy. **Conclusion:** The addition of the offset parameter d_0 improves the fitting of the data, significantly reducing the error for clinical energies.

1: Bjarngard BE, Med Phys 19:195-198 (1992).

SU-FF-T-297

Systematic Uncertainties in a Commercial Monte Carlo Electron Treatment Planning Algorithm

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Purpose: To evaluate the reproducibility of a commercial Monte Carlo dose calculation algorithm for electron beams. The Varian electron Monte Carlo (eMC) dose calculation algorithm allows the user to specify the "accuracy" of the dose calculation. Because of the stochastic mature of the algorithm, one expects that correlations between successive calculations should be minimal. **Method and Materials:** The dose distribution (per monitor unit) in a flat water phantom was calculated for multiple field sizes, with and without inserts, for multiple energies. The dose grid voxel size was 2.5 mm in all directions, and smoothing of the dose distribution was turned off. The depth dose profile was extracted by averaging the dose matrix voxels in variably-sized rectangular regions centered on or near the beam axis. Depth dose distributions were compared for different regions in the same calculation and for the same region in different calculations. **Results:** The depth doses in adjacent CT slices showed significant correlations, as expected. An unexpected result was that the depth doses in slices with up to 2.5-cm separation also showed significant correlations. Also unexpected for higher energies was that the depth dose exhibited a systematic oscillatory behavior in the region near dose maximum that was

not reduced even by averaging over a large area. Comparing the depth doses for different field sizes, the same correlations were seen. In addition, averaging the dose over multiple calculations of the same beam did not smooth out the apparent noise in the depth dose. **Conclusion:** The systematic uncertainties are approximately 1% and are most visible for higher energies because of the flat dose maximum region. The correlations seen in this work are most likely a result of complex interactions between the Monte Carlo step size and the dose grid, as well as possible reuse of particle histories.

SU-FF-T-298

The Effects of Scattering Foil Parameters On Monte Carlo Calculations of the Initial Phase-Space Data for a Clinical Electron Beam

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Purpose: To study the effects of the scattering foil geometry on the dose characteristics of a clinical electron beam using Monte Carlo simulation and discuss the feasibility of different modifications on the scattering foil for generating the electron beam phase-space data. **Method and Materials:** This work focuses on the calculation of phase-space data using BEAMnrc for a Varian Clinic 2100EX accelerator with a Type-III dual scattering foil system. To minimize the influences of other components in the system, we used a 'bare' beam (a beam without the applicator and with the jaws fully retracted) for our investigation. Using the manufacturer's specifications for the scattering foil assembly, the calculated depth doses agreed well with the measured data. The cross-beam profiles, however, showed discrepancies up to 10%. Reducing the thickness of the upper foil by 25% or doubling the thickness of the aluminum support of the lower foil led to good agreement with measured profiles. The properties of the phase-space data generated by these two different modifications of the scattering foil geometry were compared in terms of fluence, mean energy, spectrum, and angular distribution. **Results:** The two different modifications led to good agreements between calculation and measurement both in depth doses and in cross-beam dose profiles. The differences in the mean energy and angular distribution using the original manufacturer's specification and the two modifications were small (within 2%). The properties of the phase-space data generated using these two modifications were very similar. **Conclusion:** The precise scattering foil geometry is often not known. In order to obtain good agreement between Monte Carlo calculation and measured data, one may adjust the scattering foil geometry from the manufacturer's original specifications. This modified scattering foil geometry can be used to generate the phase-space data for further applications such as dose calculation in patient.

SU-FF-T-299

Validation of a Monte Carlo Algorithm for Simulation of Dispersion Due to Scattering of a Monoenergetic Proton Beam

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Purpose: A multi-leaf collimator is being designed as part of a collaborative effort to build a regional protontherapy facility. The Monte Carlo framework GEANT4 has been chosen to assist in this design by simulating the effects of changing the width of the leaves as well as the distance to the patient. The present work focuses on the validation of the current algorithm by comparing the range of the proton beam and lateral penumbra it produces with published data. **Method and Materials:** Several experimental setups have been simulated according to the data currently available for comparison. All configurations include a monoenergetic beam and a right-angled water parallelepiped where the deposited energy is sampled. We report here the specific results obtained from a variety of independent setups including a pencil beam and a 5 cm by 5 cm square beam. The proton ranges obtained for different energies are compared to tabulated ICRU values. Parameters associated with the multiple scattering dispersion of the beam are compared to published experimental data. In addition to that we compare lateral penumbra results obtained in a more realistic beam line configuration to experimental data published by the Orsay Center for Protontherapy. **Results:** The proton ranges produced agree with the ICRU values for all simulated energies. The level of reproducibility of multiple scattering effects for all the different beam profiles is adequate when compared to reference values published by Szymaowski et al. [5] The lateral penumbra produced by our beam line simulation satisfactorily corresponds to the behavior described by Oozeer et al. [4] **Conclusion:** GEANT4 is a promising tool for assisting in the design of the MLC. Our implementations reproduce to the extent presently needed, not only proton ranges but also multiple scattering and lateral penumbra effects.

SU-FF-T-300

A Comparison of Physical and Virtual Wedges: Measurement of Collimator Scatter with a Miniphantom

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Purpose: The purpose of this study was to measure the Collimator Scatter Factor S_c for Physical Wedge (PW) fields and Virtual Wedge (VW) fields with a miniphantom and to compare them. **Method and Materials:** Measurements were performed on a linear accelerator producing 6 MV and 18 MV x-rays. Data were collected from field size 4x4 cm^2 to 25x25 cm^2 and all measurements were done with miniphantom at extended SSDs and the effect of SSD on S_c was evaluated. **Results:** It is observed that the S_c values for PW fields are always higher than those of VW fields. However, for smaller field sizes upto 10x10 cm^2, the difference in S_c between PW and VW almost does not exist for all wedges. For field sizes greater than 10x10 cm^2 the difference increases with field size and upto 45° wedge angle. The maximum difference of about 3.5% occurs at 45° wedge angle for larger field size in both energies. **Conclusion:** The SSD has negligible effect on S_c for both PW and VW fields. S_c values for PW fields are always higher than that of VW fields are probably due to the general notion that PW in the beam act as additional extended source of scatter radiation. While there is a significant difference in S_c values for 45° wedge for larger field size, there is negligible difference for smaller field sizes upto 10x10 cm^2 for all the wedge angles in both energies. It is most likely due to scattered radiation from the irradiated wedge volume that increases with the field. It is further observed that for PW, the scatter increases with the wedge thickness at the central axis. The S_c values for PW 60° fields are less than those for PW 45° fields due to less wedge thickness at the central axis.

SU-FF-T-301

A Practical Method Evaluating the Effectiveness of the Existing Vault Shielding for IMRT

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Purpose: To re-evaluate shielding of the existing linac vault due to the recent implementation of IMRT in a community center. While the prescribed dose per fraction to the treatment volume remains the same, IMRT delivery requires a much higher number of monitor units (MU). It is estimated that the required number of MU needed for IMRT treatment increases by a factor of two to five over conventional techniques. This increase in MU per fraction has a direct impact on the shielding of the vaults used to deliver IMRT. **Method and Materials:** Two methods were used for the evaluation. The first method incorporated a radiation survey, a modified Modulation Scaling Factor (MSF_{mod}) and a gantry use factor. The results were compared to the current regulatory guidelines. The second method analyzed the area and personnel film badges, by reviewing the records of the area and personnel radiation monitoring for a two year period. During the first year, the prostate patients received only conventional 3D treatments with 15MV photons. In the second year, IMRT utilizing 6MV photons was offered to all prostate patients. The area monitors were placed on the door to the vault. Technologists assigned to this vault before and after IMRT introduction were also identified **Results:** Radiation exposure results of the area and personnel monitoring decreased from the first year to the second, due to reduced production of neutrons from the decrease in use of 15MV photons. Radiation surveys identified two previously unidentified areas of radiation levels above background, but not in excess of the regulatory limits for radiation exposure. **Conclusion:** The radiation survey demonstrated that the existing shielding was effective for the increased IMRT workload. Standard personnel and area dosimeters, available from commercial dosimetry vendors, can also be used effectively to demonstrate and document continued compliance with evolving treatment modalities.

SU-FF-T-302

A Secure Web-Based, Real-Time System for Peer-Review, Quality Assurance and Clinical Outcome Studies in Radiation Therapy

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Purpose: To develop a secure, integrated relational database and a system of web-based client applications for radiation therapy data submission, archiving, retrieval and data mining for performing peer-review, quality assurance and clinical outcome studies. **Method and Materials:** The Resource Center for Emerging Technologies (RCET) System was developed at our institution to support NCI sponsored advanced technology clinical trials. This system features multi-tiered distributed client-server architecture; content-based relational database for data storage (supports DICOM, DICOM-RT, RTOG and common electronic image formats), retrieval and data mining; web-based client applications for data submission and rapid review. The RCET System has the necessary tools for peer-review and quality assurance of radiation therapy planning data.
Clinical outcome studies are currently conducted in our research office through a labor intensive process. Data are collected manually in code sheets and entered into a simple database. Clinical data are manually retrieved and analyzed for outcomes.
We propose to automate this process by fully utilizing the RCET infrastructure. Customized web-based applications and protocol specific data forms are added. Patient and treatment records from hospital information system (HIS), facility management system (FMS) and treatment planning system (TPS) are extracted and automatically archived. Data mining, rapid review and reporting tools designed for outcome studies are added. **Results:** The RCET infrastructure has been developed and extensive field testing is underway. Electronic data entry forms have been developed with automatic upload into the RCET database. Data from HIS, FMS and TPS have been extracted. New tools are added for outcome studies. **Conclusion:** The RCET system has the necessary tools for peer-review and quality assurance of radiation therapy planning data. Extension of RCET to support clinical outcome studies is feasible and cost-effective. Proactive in addition to retrospective studies are possible.

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SU-FF-T-303

Characteristics of Induced Activity From Medical Linear Accelerators

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Purpose: To investigate radiation protection issues related to induced activity in typical medical linear accelerators (linac). **Method and Materials:** A calibrated ionization chamber survey meter was used to measure the induced activity on Clinac 2300C/D using a standard setup: 18 MV photon beam, 10×10 cm^2 field, a dose rate of 400 MU/min, and two points of measurement: machine isocenter (point I) and on the isocenter axis 1 m off the isocenter (point C). The experiments were carried out in early mornings before clinical work to maintain a steady radiation background for the measurements. **Results:** Higher beam energy, higher dose rate, larger field size, and the use of multileaf collimators result in higher activation levels at the isocenter. The induced activity decays faster for a larger field and longer irradiation times. The activation level reaches its practical saturation value (0.04 mSv/h at point I) after about 30 min of irradiation. Successive "doses" of 300 MU were given every 15 minutes to determine the trends in the activation level (6 - 8 μSv/h at point I) in a typical clinical mode. As well, a long- term (85 hours) decay curve was measured to evaluate the long-term decay of room activation after a typical day of clinical linac use. A mathematical model for the activation level at the isocenter has been established and shown to be useful in explaining and predicting the induced activity levels. **Conclusion:** Typical residual exposure rate in the morning before clinical use of the linac is ~1 μSv/h and 0.6 μSv/h for points I and C, respectively. A whole day of clinical use of a high energy linac can raise the activation level about 30% compared to the level after the first irradiation. More than 70% of the induced activity will decay within one hour after an irradiation.

SU-FF-T-304

Characteristics of Neutron Equivalent Dose Around Medical Linear Accelerators

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Purpose: To investigate the characteristics of neutron equivalent dose (*NED*) around medical linear accelerators (linac). **Method and Materials:** Two types of bubble detectors (BD-100R for fast neutrons and BDT for thermal neutrons) were used to measure the neutron equivalent dose. Most experiments were carried out using a Varian Clinac 2300C/D linac, 18 MV photon beam at two points of measurement: machine isocenter (point I) and on the isocenter axis 1 m off the isocenter (point C). **Results:** The *NED* at point I is 12.7 mSv_n/100 MU (10% is from thermal neutron) and this dose decreases to 1.7 mSv_n/100 MU (13%) at point C. The *NED* at point I increases with the increasing field size, whereas the *NED* at point C exhibits the maximum value for a 10×10 cm^2 field. The use of a multileaf collimator (MLC) increases the *NED* at point C but does not show any significant effects for the *NED* at point I. In order to facilitate conversion of *NED* in air to *NED* in tissue so that the patient photoneutron dose can be estimated, a new quantity *NTAR* (neutron tissue-air ratio) is introduced and measured in this work. As well, a *NED* depth dose curve is determined. Inverse square law can not be applied to the *NED* results measured at different positions along the central beam axis. **Conclusion:** Photoneutrons produced by a high energy photon beam delivers to the radiotherapy patient a equivalent dose of about 1% of the treatment dose inside the treatment field and 0.1~0.3% outside of the treatment field. The dose inside the field increases with the increasing field size, while the dose outside the field decreases with the increasing field size. *NTAR* provides an easy method for the conversion of *NED* in air to *NED* in tissue.

SU-FF-T-305

Comparative Workloads for Four Multi-Modality Linacs in Two Facilities

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Purpose: Physicists performing radiation shielding calculations and post-construction surveys conservatively assume linacs will be used at highest energy (23X) and largest field sizes (FS) (40 $cm)^2$ for equal times at primary angles (PA) (0^0, 90^0, 180^0, and 270^0). Intensity modulated radiation therapy (IMRT) use challenges these assumptions. How are linacs used in IMRT programs? **Method and Materials:** From patient records, we performed a daily workload analysis for four linacs in two facilities. Facility X, a Veterans Affairs (VA) hospital, Varian 2100C, has no IMRT program and treats male patients with standard methods. Facility Y, a university hospital, treats male and female patients with three Varian 21EX linacs. Linac B treats conventional non-IMRT patients, C treats conventional and IMRT prostate patients, and D treats IMRT head and neck patients, conventional patients, and patients requiring 6X total body irradiation. This unit was analyzed excluding (D-NoTBI) and including (D-TBI) TBI treatments. **Results:** Results are presented as follows: VA, B, C, D-NoTBI, and D-TBI. Daily ports and patients were: (165, 47); (78, 28); (98, 30); (77, 19); (86, 20). Daily beam times (min) were: 30,15, 21, 25, and 55. Modality uses (6X, 18 or 23X, EB) were: (16%, 81%, 3%); (37%, 59%, 4%); (40%, 57%, 3%); (85%, 15%, 0%); (86%, 14%, 0%). Minimum, average, and maximum FS, excluding TBI, were similar (6 $cm)^2$, (14 $cm)^2$, and (23 $cm)^2$. Use at other than PA varied from a minimum (VA; 9%) to a maximum (D NoTBI; 48%). Data for average depths and doses will be presented. **Conclusion:** A 50% 6X IMRT use decreased, by 50%, patients treated daily but beam time decreased only 15%. 6X use increased to 85% and non-PA use increased by 48%. 6X TBI treatments can double beam use. Consequences for facility designs, programs, and radiation surveys will be presented.

SU-FF-T-306

Credentialing Requirements for NSABP B-39 / RTOG 0413

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Purpose: NSABP B-39 / RTOG 0413 is a Phase III trial comparing Whole Breast Irradiation versus Partial Breast Irradiation (PBI). The partial breast

arm consists of 3 techniques, 3D Conformal Radiation Therapy, MammoSite and multi-catheter HDR. For each of these techniques an institution, radiation oncologist and physicist "team" must be credentialed. Credentialing requires completing knowledge assessment and facility questionnaires, importing a DICOM CT image set, performing a treatment plan using the image set and exporting the images, structures and isodoses to the Image-Guided Therapy QA Center (ITC). **Method & Materials**: An institution can obtain the Knowledge Assessment and Facility Questionnaires from the RPC's website (http://rpc.mdanderson.org). These questionnaires can be completed online, emailed, faxed or mailed directly to the RPC. An institution may be credentialed for one or more of the PBI techniques. A CT benchmark case exists for each PBI technique. The institution is required to import the appropriate CT image set into their treatment planning system. The benchmark must be planned per protocol. The benchmark must then be digitally exported to the ITC along with all required hard copy data. The RPC will review each benchmark case submitted. Once the RPC has completed its review NSABP will be informed that the institution has met the requirements for credentialing and will be allowed to enter patients onto the protocol. **Conclusion:** The purpose of credentialing is to verify that the radiation oncologist and other personnel involved are familiar with the protocol and can plan a case per protocol prior to placing a patient on protocol. This process enables us to give a "team" feedback prior to treating a patient on the trial potentially enabling us to reduce the number of deviations incurred on the trial.

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SU-FF-T-307

Determination of Optical Properties in Semi-Infinite Media

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Purpose: To develop a method to quickly determine tissue optical properties (absorption coefficient μ_a and transport scattering coefficient μ_s') in a semi-infinite medium. **Method and material:** Optical properties where determined by measuring the ratio of light fluence rate to source power along a linear channel at a fixed distance (4 mm) from an isotropic point source. The light detection system consists of two parallel light transmitting catheters placed 4mm apart. Diffuse light, from a 2mm cylindrical diffusing tip, is collected by an isotropic detector with a 0.5mm scattering bulb whose position is determined by a computer controlled step motor, with a positioning accuracy of better than 0.1 mm. The system automatically records and plots the light fluence rate per unit source power as a function of position. The result is fitted with a diffusion equation to extrapolate μ_a and μ_s'. Measurements where made in liquid tissue simulating phantoms, with known reduced scattering coefficient (μ_s') and absorption coefficient (μ_a). A theory based on light source on semi-infinite medium has been developed to interpret the measured data. To test the ability of this algorithm to accurately recover the optical properties of the tissue, we made measurements in tissue simulating phantoms consisting of Liposyn concentration of 0.53% ($\mu_s' = 3.68 cm^{-1}$) in the presence of Higgins black India ink at concentrations of 0.002, 0.012 and 0.023% ($\mu_a = 0.1 - 1$ cm^{-1}). For comparison, the optical properties of the phantom were determined independently using broad-beam illumination. **Results:** We find that μ_a and μ_s' can be determined by this method with a standard (maximum) deviation of 24% (27%) and 29% (42%) for μ_a and μ_s', respectively. **Conclusion:** We developed a model for quick and accurate determination of tissue optical properties in semi-infinite medium, which is theoretically suitable for determination of optical properties for esophagus PDT.

SU-FF-T-308

Determination of Output, Percentage Depth Dose (PDD) and Effective Source to Skin Distance (SSDeff) for Irregular Electron Fields

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Purpose: The sector integration method (SIM) has been described in the literature as a simple alternative to calculate the output for irregular electron fields. However, full characterization of the electron beam data (output and PDD) is necessary for the clinical use. The purpose of this work is to develop and commission new software using the SIM to calculate the output, PDD and SSD_{eff} for irregular electron fields, compare the results with pencil beam algorithm calculation and measured data. **Method and Materials:** A Clinac 2300CD (Varian) with energies of 6, 9, 12, 15, 18 and 22 MeV was used. A set of circular electron cut-outs, of different radios, were made for applicator sizes of 6x6 cm. and 15x15 cm. Measurements were done with a PTW Markus ionization chamber, an automatic phantom (Scanditronix-Wellhofer) for PDD and a standard water phantom for output and SSD_{eff} determination. Software was developed using Delphi 6.0. This software divides the irregular field in sectors (4, 8, 16, 32) and average the contribution for each one. A set of 15 cut-outs (square, rectangular and irregular) were build for verification. For each cut-out and electron energy the output, PDD and SSD_{eff} were calculated with the new software and compared to chamber measurements. The treatment planning system (TPS) CadPlan (Varian) was used to calculate PDD. **Results:** The measured and calculated output differences for rectangular and squares fields were less than 1% and for irregular fields less than 3%. The PDD variations between measured and new software calculated were smaller than 2mm. The new software PDD agrees within 2mm with the TPS and ion chamber measurements, except for 6MeV were the differences were less than 3mm. **Conclusion:** The new software offers a simple and exact tool to calculate output and PDD curves for irregular electron fields with errors clinically acceptable.

SU-FF-T-309

Dosimetric Study of Grid Therapy Using a Multileaf Collimator

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Purpose: The purpose of this work is to show the feasibility of using multileaf collimators (MLCs) for grid therapy. **Method and Materials:** A Varian 21EX linear accelerator equipped with a 120-leaf MLC was used to shape multiple openings of either $0.5x0.5cm^2$ or $1x1cm^2$ in a hexagonal pattern over an area of $10x10cm^2$ or $20x20cm^2$, respectively (at 100cm from the source). The total field was delivered in a sequence of 5 beams each defining two columns of the opening at a time. The dose profiles at various depths in a solid water phantom were measured using Kodak EDR2 films and analyzed with RIT dosimetry system. The dose profiles were then compared to those obtained with conventional grid collimators of similar holes and grid sizes. To evaluate the role of MLC leakages on the dose distribution, Monte Carlo simulations were performed to establish the physical dose limit in the blocked area. **Results:** At the depth of 1.5 cm, the blocked area receives at most 10% of the peak dose in the exposed area for the 1cm grid, and 21% for the 0.5cm grid. These are comparable to the 13% and 18% obtained using the grid collimators. The theoretical values for a hypothetical leakless MLC are found to be 5% and 12%, respectively. At the depth of 10cm, the relative dose in the blocked area increase to 18% and 25% with the MLC grids and 19% and 29% with the grid blocks, respectively. The respective output factors as normalized to open fields are 80% and 65%. **Conclusion:** The MLC grids give the valley-to-peak dose ratios and output factors that are comparable to those of cerrobend grid collimators. The advantages of MLC are clear: the grid field can be obtained easily and quickly by simply programming the leaf positions, and it is cost-effective.

SU-FF-T-310

DVH Analysis: Consequences for Quality Assurance of Multi-Institutional Clnical Trials

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Purpose: The submission of digital treatment planning data is essential for quality assurance (QA) of multi-institutional clinical trials involving advanced technology delivery techniques. Digitally submitted Dose Volume Histograms (DVHs), however, lack consistency due to algorithmic differences among Treatment Planning Systems (TPSs). To maintain consistency among cases in multi-institutional clinical trials, the Image Guided Therapy QA Center (ITC) re-calculates DVHs from submitted 3-D dose distributions and structure contours. In some recent trials involving high dose gradients, sizeable discrepancies have been observed between DVHs re-calculated by the ITC and DVHs submitted by participating institutions, making QA review of these data more difficult. **Method and Materials:** Digitally submitted DVH data were collected from various

commercial TPSs for protocols requiring digital data submission. Submitted structure volumes and DVHs were compared to those calculated by the ITC. Comparisons were performed for anatomic structures ranging in size from < 1cc (optic chiasm) to > 450 cc (Lung PTV). **Results:** Agreement between submitted and re-calculated DVHs varied with the spatial sampling algorithms used by TPSs and improved as the volume of structures increased. Discrepancies in excess of 15% were observed for structures with volumes < 50 cc. **Conclusion:** Discrepancies in DVHs calculated by various commercial TPSs have long necessitated re-calculation of DVHs by the ITC for consistent correlation of dosimetry with outcomes. With increasing dose gradients, however, small changes in computed volumes can result in significant differences between dose coverage statistics reported by the treating institution and those computed for QA review. As a result, apparently protocol-compliant plans may be judged to violate QA criteria when submitted data are reviewed. Our analysis of DVH discrepancies among various TPSs can help to set QA criteria for present and future protocols, especially those in which high dose gradients are required.

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SU-FF-T-311

Exposure of An Ultrasound System for Prostate Localization to Neutrons

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Purpose: Ultrasound systems are commonly used for confirming prostate localization. At our center, these devices are used for both photon and proton treatments. The question arose as to whether the neutron environment in the proton room would adversely affect their operation and, lacking any manufacturer's information regarding neutron exposure to the instrument, it was decided to determine the neutron dose around the ultrasound unit in a treatment room housing a 6/18 MV linear accelerator. **Method and Materials:** The ultrasound device is stored at the side of the room when not in use, close to the primary beam for a gantry angle of 90°. TLDs were placed on all four sides of the device, on the wall along the gantry rotation axis and on both sides of a short maze. The purpose of the TLDs on the walls was to provide a constancy check; this was particularly true for the TLD on the gantry axis since the readings should be independent of the gantry angle. **Results:** Six sets of TLDs were left in for periods of 16, 5.5, 4, 2, 1 and 2 days. For those periods, the number of MUs delivered to all the patients was computed using the record and verify system. The average number of MUs per day for both energies was 16,000 ± 20% and for 18 MV was 7,900 ± 9%. The variation is due to the change in the number of IMRT treatments delivered with time. The results are 0.366, 0.145, 0.140 and 0.176 mrem/MU (proximal/distal to source; proximal/distal to beam) for neutrons and 0.230, 0.083, 0.078 and 0.176 mrem/MU for photons. **Conclusion:** Based on use till now, the results establish a lower limit of 1650 rem on the neutron dose that the ultrasound system can tolerate.

SU-FF-T-312

Feasbility Study of Orthogonal Bremsstrahlung Beams for Improved Radiation Therapy Imaging

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Purpose: To study the feasibility of using orthogonal bremsstrahlung beams for imaging in radiation therapy. The orthogonal bremsstrahlung is produced in linac targets in directions perpendicular to the incident electron beam. **Method and Materials:** BEAMnrc MC modeling was used to design different targets and to obtain energy spectra and relative intensities of orthogonal beams as well as forward-directed beams. The reliability of the simulations was checked by comparing results with benchmark experiments. Two different targets and a collimator were designed and built. The primary electron beam from the research port of a Varian Clinac-18 accelerator impinging on Al and Pb targets was used to create orthogonal beams. For these beams diagnostic image contrast was tested by placing simple Lucite objects in the path of the beams and comparing image contrast obtained in orthogonal to forward direction. **Results:** The simulations showed that a thickness of 80% of CSDA range is sufficient to completely remove electron contamination in the orthogonal direction. The intensity of the orthogonal beam for high-Z targets is larger compared to low-Z targets by a factor 20 for W compared to Be. For a 6 MeV electron beam, the average energy for low-Z targets is lower (330 keV for Al, 170 keV for Be) compared to high-Z targets (900 keV for Pb) and lower compared to the forward beam (0.56 MeV, 0.8 MeV and 1.4 MeV for Be, Al and Pb, respectively). For irradiation times of 1.2 s in electron mode the contrast of diagnostic images created with orthogonal beams from the Al target is superior to that in the forward direction. **Conclusion:** Because of the lower average energy of orthogonal beams, image contrast obtained with these beams is superior. This study confirms feasibility, both in terms of intensity and image contrast, of orthogonal bremsstrahlung beams in radiation therapy.

SU-FF-T-313

Impact On Tumor Dose Coverage Due to the Second Buildup for Lung Tumour Treatment Using An 18 MV Photon Beam

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Purpose: Conformal radiotherapy requires accurate dose prediction in the planning target volume and organs at risk. This study is to investigate the target dose coverage in lung tumor treatment and to assess the impact of the second dose buildup as a function of irradiated field sizes when an 18 MV photon beam is used. **Method and Materials:** The Monte Carlo codes BEAMnrc/DOSXYZnrc are used to simulate photon beams from a Varian accelerator and to calculate dose distributions in a lung phantom. The dose distributions in lung and tumor were calculated for various field sizes to investigate the effect of the incident field size. The Monte Carlo calculated dose distributions are also compared with those predicted by commercial treatment planning systems. **Results:** There is no significant tumor dose reduction (<1%) due to the second buildup for treatment field sizes >10×10cm^2 for an 18 MV photon beam treated with parallel opposed beams. However there are about 4% to 12% dose reductions at the interface due to the second buildup when treatment fields are 7×7cm^2 to 3×3cm^2 respectively. The simple inhomogeneity correction methods (Batho and ETAR) employed in a commercial treatment planning system can give rise to inaccuracies up to 20% in the lung and tumor dose for a small field. **Conclusion:** There is a benefit to using a higher energy 18 MV beam for larger treatment fields (>8×8 cm^2) to reduce hot spots and there is negligible dose reduction at the interface due to the second buildup. However the second buildup can cause significant dose reduction at the interface for field sizes <7×7 cm^2 and an 18 MV beam should be not be used for a small fields in the lung. Batho or ETAR correction methods result in large errors in predicting the dose in lung and tumor for a small field.

SU-FF-T-314

Initial Monte Carlo Analysis of the Dosimetric Effects of Gold Nanoparticle Radiosensitizers

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Purpose: Monte Carlo simulations have been undertaken to quantify the dosimetry of tumors that have absorbed nanoparticle gold as radiosensitizers and irradiated with various radiotherapy modalities. **Method and Materials:** EGSnrcMP and BEAMnrcMP, well known and documented Monte Carlo Photon Transport simulation codes are used for therapy simulations. Previous measurements of uptake ratio's provide a basis for generating new radiation interaction cross sections for use in radiation transport simulations. Cross sections generated by the simulation software are checked against cross sections generated using the NIST (National Institute of Standards and Technology) Standard Reference Database 8 (XGAM) and found to agree to within about 0.5%. 250 kVp, and 6 MV and Ir-192 HDR spectra provided with the EGS package where used as sources. Tumors containing 0.5% to 5% Au by weight (the balance made up by water) and sized from 0.5 to 3 cm were simulated at various depths and compared to pure water. The effects of normal tissue absorption of gold in media surrounding the tumor were also investigated. **Results:** As expected, 250 kVp orthovoltage units showed the largest benefit from nanoparticles. A 50% absorption increase in tumors absorbing 1.5% Au by weight. Ir-192 therapy beams available from High Dose Rate Brachytherapy units treating 1.5% and 5% nanoparticle gold by weight showed a 13% and 38% increase in dose absorption rate for tumors 1cm from the source. 6MV photon beams treating a 3cm tumor at 10cm depth showed a modest 5% improvement. Surrounding media absorption of gold

nanoparticles shifts both target and surrounding tissue absorption rates higher, but does not significantly change their relative absorption rates. **Conclusion:** These simulations suggest gold nanoparticles in some modalities are worth investigating as radiosensitizers. Initial research should focus on HDR modalities first.

SU-FF-T-315

Measurement of the Leakage From Linear Accelerators in the Backward Direction for 4, 6, 10, 15 and 18 MV X-Rays

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Purpose: NCRP 49 stipulates that the x-ray leakage from the housing of an x-ray source > 500 kV should be no more than 0.1% of the useful beam exposure at 1m from the source. This figure is used by manufacturers to design the shielding in linacs and by physicists when designing room shielding. It is expected that the machine leakage in the backward direction would be less since the gantry and stand contain significant amounts of metal to attenuate x-rays. **Method and Materials:** X-ray leakage has been measured from linacs having energies of 4, 6, 10, 15 and 18 MV using chambers and TLDs. Measurements were made for 9 positions at the rear wall in the linac room on a 2m x 2m grid covering one side of the linac, starting from a line through he isocenter and target, and for the four cardinal gantry angles: 0°, 90°, 180° and 270°. A 100cc ionization chamber was used because of its high sensitivity; the chamber was calibrated against a Farmer chamber using the method of Biggs and Nogueira[1]. The TLDs read neutron as well as x-ray dose. **Results:** The ion chamber results show that the leakage is greatest when the gantry is horizontal with the head on the same side as the chamber and least when it is on the opposite side. The readings for gantry angles of 0° and 180° lie midway between those extremes. The greatest leakage is for 10 MV (0.041%), followed by 18 MV (0.028%), 6 MV (0.016%), 15 MV (0.011%) and 4 MV (0.006%) [numbers refer to average of 9 points]. **Conclusion:** These average values are significantly lower than 0.1%, although at some locations, the value does exceed 0.1%, but only for 10 and 18 MV

[1] Biggs PJ and Nogueira IP, Med. Phys. 26:2107-2112; 1999

SU-FF-T-316

Modifications to the "three-Source Model" for the Calculation of Head Scatter Factors for Small Field Sizes

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Purpose: The three-source model proposed by Yang et al.[1] when applied to Siemens PRIMUS 6 MV beam over-estimated head scatter by 10-200% for field sizes less than 2 cm x 2 cm and elongated narrow beams. This necessitated the development of a modified approach **Method and Materials:** The complete theoretical background for the three–source model can be found in the published literature[1] in which the total energy fluence at the point of calculation can be divided into three components. The primary component Cp has been chosen around 90% in the model. A modified approach is proposed to the three-source model with the primary source component Cp having growth function that grows exponentially with radius of the beam in the Sp plane. The primary source function was integrated in the Sp plane using the formula, $Cp = Cp3*(\exp(-r_s*Cp2)$; $rs < r_3$ where Cp2, Cp3 and r_3 are fitting coefficients. **Results:** The measured head scatter factors for smaller field sizes including the rectangular fields where the exchanged collimator jaw positions have been compared with both three-source model and modified three-source model for Siemens PRIMUS 6 MV beam. It was observed that the accuracy of the modified model is improved and is within 10% of the measurements for small field sizes. **Conclusion:** In routine IMRT treatments, about 10-15% of the segmented fields use small or elongated fields. The modified approach to the three-source model improves the accuracy of the head scatter factors calculation significantly for field sizes below 2 cm x 2cm.

Reference: 1. Y. Yang, L. Xing, A.L. Boyer, Y. Song and Y.Hu, A three-source model for the calculation of head scatter factors. Medical Physics: 29(2002) p2024-2033.

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SU-FF-T-317

Options for SURLAS Design Modification Due to the Impact of Ultrasound Nonlinear Propagation

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Purpose: To study the impact of acoustic nonlinear propagation on the operation of a Scanning Ultrasound Reflector – Linear Arrays System (SURLAS) and determine possible options to modify its existing design. **Method and Materials:** The SURLAS is a superficial ultrasound hyperthermia system for the delivery of simultaneous (and sequential) thermoradiotherapy. Heat is delivered by dual-frequency scanned planar ultrasound while radiation is delivered with external beam radiation. Compatibility between the SURLAS and a Linac requires an applicator design where ultrasound waves (1) are of higher intensity and (2) travel longer distances than usual. Hence, ultrasound waves, especially from a 4.9 MHz array may be affected by nonlinear propagation (i.e., finite amplitude effects) which causes a dramatic increase in ultrasonic attenuation in the water coupling medium inside the applicator. Ultrasound propagation for the SURLAS applicator was analyzed to identify possible options in design modification to minimize the impact of nonlinear propagation on acoustic output. **Results:** Results are given in terms of limits on maximum power output (MPO), maximum traveling distance (MTD), and maximum frequency (MF) that could be used for hyperthermia delivery. The effects of these parameters on the applicator's design and performance, along with options for adjusting its current design, are discussed. **Conclusion:** A compromise must be reached between MTD and MF for a given required MPO. For example, for a typical chest wall for a frequency of 4.9 MHz, the MTD must be < 11.2 cm. If the current distance of 16 cm is kept, the MF must be < 2.15 MHz. In sum, this work suggests potential solutions for the SURLAS applicator design for specific treatment sites in order to provide sufficient and sustainable heating of tissue during simultaneous thermoradiotherapy.

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SU-FF-T-318

Peripheral Doses From Pediatric IMRT

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Purpose: Peripheral dose (PD) data exists for conventional and IMRT delivery to standard adult sized phantoms. Pediatric PD reports are limited to conventional therapy and are model based. Our goal was to ascertain whether data acquired from full phantom studies and/or pediatric models, with IMRT modifiers, could predict Organ at Risk (OAR) dose for pediatric IMRT. As monitor units(MU) are greater for IMRT, it's expected IMRT PD will be higher, potentially compounded by smaller phantoms. **Method and Materials:** Five patients with cranial lesions were chosen. Conventional 3D plans for the same patient/target/dose(180cGy), were optimized without limitation to number of fields or wedge use. 6MV, 120-leaf Varian axial beams were used. A "3-year-old" phantom was configured per CDC data. Micro(0.125cc) and cylindrical(0.6cc) ionization chambers were appropriated for the thyroid, breast, ovaries, and testes. PD were recorded by electrometers set to the 10^{-10} scale. Each system set was calibrated to the dose range. Attention was paid to field sizes and MU. **Results:** Thyroid dose was lower for IMRT delivery than predicted or for 3D, (ratio of IMRT/Conventional ranged from 0.47-0.94), doses ~[0.4-1.8cGy]/[0.9-2.9cGy]/fraction, respectively. Prior reports are for fields 10cm or greater, while pediatric CNS fields range from 4 to 7cm and effectively much smaller for IMRT(2-3cm). This close proximity (~ 7.5 cm from field edge) is dominated by internal scatter, therefore field size differences overwhelm phantom size affects and increased MU. Distant PD dominated by head leakage, were higher than predicted, even accounting for MU (~factor of 3) likely due to the pediatric phantom size. The ratio of testes dose ranged from 3.3-5.3 for IMRT/Conventional. **Conclusion:** PD to OAR for Pediatric IMRT cannot be predicted from with large field, full phantom studies. For regional OAR, doses are likely lower than predicted by existing data, while distant PD are higher.

SU-FF-T-319

Reconstructing Dose Distributions From Portal Images with a Backprojection Dosimetric Algorithm

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Purpose: To develop a backprojection dosimetric algorithm for dosimetric verification. The algorithm reconstructs a three dimensional dose distribution from the treatment beams' portal images and the CT images for a patient/phantom. **Method and Materials:** The reconstruction process covers four steps: (a) To acquire a portal image with an electronic portal imaging device(EPID) and convert it into a transmission dose distribution on EPID plane. (b) To reconstruct the incident primary dose distribution from the transmission dose distribution. (c) To calculate the primary dose distribution in the phantom using the phantom's CT image set. (d) To calculate the scatter dose distribution by superposing the scatter kernels in the patient/phantom; then to make the summation of the primary and the scatter dose distribution to get the total dose distribution in the patient/phantom. The dosimetric algorithm was implemented in a C program and applied to five phantoms, which were homogeneous, inhomogeneous, regular or irregular, irradiated by a regular-shaped, irregular-shaped or intensity-modulated beam. The calculated dose distributions were compared with the measured ones. **Results:** For all the experiments, the agreement between the calculated and measured dose distribution was within 5% in the field areas with low dose gradients. Large deviation happened to the field edge in the lung, which had a low density. **Conclusion:** The accuracy of the developed backprojection dosimetric algorithm can meet the requirement of clinical dosimetric verification. But the algorithm should be improved furthering in order to calculate the dose in the region of electronic disequilibrium accurately.

SU-FF-T-320

Simple Acoustic Beam Model for Thermoradiotherapy Implemented in An Open Source Treatment Planning Research System

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Purpose: Several clinical trials have shown that hyperthermia can significantly increase both local tumor control rates and duration of local control, significantly improving the quality of radiation treatment. No existing treatment planning systems provide tools for planning and analyzing thermal and radiation doses simultaneously in the same volume of interest. We propose to modify our Matlab-based open-source-code system CERR (Computational Environment for Radiotherapy Research) for the development of thermoradiotherapy treatment planning (radium.wustl.edu/cerr). **Method and Materials:** We implemented a simple exponentially attenuated acoustic beam model in CERR, accounting for reflection, transmission and refraction of the primary beams. The model applies to sub-volumes that are assumed "homogeneous" (air, soft tissue, bone), that make up a composite "heterogeneous" total computational volume, and that account for interface phenomena, i.e. reflection, transmission and refraction of the primary beams at impedance mismatched interfaces between sub-volumes. **Results:** We calculated the SAR (specific absorption rate) for a single acoustic beam at 3.5 MHz for a chest wall breast plan. The field size was 12cm x 12cm. Calculation of a single beam takes approximately 60 seconds for plan size of 512x512x131 voxels. The power deposition of this beam for the CERR plan is shown. An attenuation profile for the beam is shown. The model correctly shows zero SAR values outside the beam and in the lung areas. **Conclusion:** We propose tools to display SAR, temperatures, thermal doses, hybrid thermo-radio-therapy doses, etc., simultaneously, along with calculation of volume histograms for the various dose parameters. Significant advances in clinical thermoradiotherapy have been hampered by the lack of advanced treatment planning systems. We are embarking on a long-term project to develop a CERR-based system for superficial ultrasound hyperthermia that includes implementation and validation of complex acousto-thermal numerical models. The system will be freely distributed to the hyperthermia research community for IRB-approved research.

SU-FF-T-321

Spatial and Contrast Resolution of a New Electronic Portal Imaging Device

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Purpose: A new amorphous silicon portal imager has become available which can be operated in two spatial resolution modes and can gate the beam to avoid irradiating the patient during imager dead time. This study will evaluate the spatial and contrast resolution of this device. **Method and Materials:** A diagnostic imaging phantom was placed near isocenter of a megavoltage linac and the portal imager was located 40 cm below the phantom. Near the center of the phantom are 21 groups of five bars and four spaces of various widths. Around the perimeter of the phantom are 18 circular details of various thicknesses. Spatial resolution was determined by locating the highest frequency pattern that could be resolved in the portal images. Contrast resolution, dominated by photon statistics, was evaluated qualitatively by comparing the number of contrast details visible in images of two to eight MU for each scanning mode. **Results:** With the imager in half resolution mode neighboring pixels are binned together resulting in pixels that project to approximately 0.6 mm at isocenter. In this mode 0.8 line pairs/mm can be resolved. In the un-binned mode the spatial resolution is increased to only 0.9 line pairs/mm, as the focal spot size of the accelerator begins to dominate the resolution. Contrast resolution is shown to depend on integrated dose. When the imager holds the beam during readout dead time photons are collected more efficiently and contrast resolution for a given MU set is improved compared to the un-gated acquisition. **Conclusion:** Operation of the imager in full resolution mode results in modest improvements in spatial resolution. Contrast resolution for a given MU set is improved by the imager's ability to gate the beam during readout dead time.

SU-FF-T-322

Statistical Analysis of Failures of a Medical Linear Accelerator Over Ten Years

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Purpose: In order for better management of a medical linear accelerator. the records of the operational failures of Varian CL2100C over ten years were analyzed. **Method and Materials:** The failures were classified according to the involved functional subunits and each class was rated into three levels depending on operational conditions. The relationship between the failure rate and working ratio and the relationship between the failure rate and outside temperature were investigated. in addition, the average life time of main part and operating efficiency for last 4 years were analysed. **Results:** Among the recorded failures (total 587 failures), the most frequent failure, which was 20% of the total, was observed in the parts related to the collimation system including monitor chamber. Regarding to the operational conditions, the 2nd level of failures, that temporally interrupted treatments, was the most frequent. The 3rd level of failures, that interrupted treatment for more than several hours, was mostly caused by the accelerating subunit. The number of failures was increased with number of treatments and used time. The average life-time of a Klystron and Thyratron became shorter as the working ratio increased, which was 42 and 83% of the expected values, respectively. The operating efficiency of 95% or higher was maintained, but value slightly decreased. There were no significant correlations between the number of failures and outside temperature. **Conclusion:** Recording equipment problems and failures in detail over a long period of time can provide a good knowledge of equipment function as well as the capability to forecast future failure. More rigorous equipment maintenance is required for old medical linear accelerator to avoid the serious failure in advance, and improve the patient treatment quality.

SU-FF-T-323

Sub-Millimter Image Based Radiotherapy Treatment System for Small Animals

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Purpose: The sub-millimeter animal imaging modality is a new field for study molecular or animal images. Such high resolution images can help us study radiation-induced biological response in small animals. The spatial

resolution of current used human treatment system is at least 2 mm, which is too large for the organ dimension of a mouse (5 mm). We have developed an animal RT system based on a Varian Clinac 2100, and a dose calculation kernel using BEAMnrc. **Method and Materials:** As the result of lateral electron disequilibrium, it is difficult to measure dose characteristic for small beam field. Therefore, our Monte Carlo simulation was verified with a small volume ion chamber and a PTW diamond detector for a larger beam (6MV, Varian Clinac 2100 equipped with a BrainLab 14mm cone). More verification is performed for 4mm, and 6mm cones. A 5-cm long cylinder with a radius of 1.5 cm is modeled as the head of mouse. We have calculated the dose distribution inside this cylinder for 1-portal, 4-portal, and 192 degree arc irradiation. **Results:** The PDD and profile from measurement and simulation agree to each other for 14mm cone within 0.5% or 0.5 mm. If fitting PDD, we can observe that the curves after D_{max} decays exponentially. The dose distribution inside the cylinder modeling mouse's head is too sharp for 1-portal and 4-portal exposures, which recommends the arc technique as a better approach. **Conclusion:** We have demonstrated that it is feasible to build a small animal RT system using Varian Clinac 2100 with cones and Monte Carlo dose calculation kernel.

SU-FF-T-324

The Use of Megavoltage CT (MVCT) Images for Dose Recomputation

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Purpose: Megavoltage CT (MVCT) images of patients are acquired daily on a helical tomotherapy unit (TomoTherapy, Inc., Madison, WI). These images are used in clinical practice for patient alignment; however, they can also be used to recalculate the treatment plans in the patient's anatomy. Prior to using this tool to evaluate clinical plans, a series of phantom based end-to-end tests were run to test the use of MVCT images for dose recomputations. **Method and Materials:** A CT to electron density phantom was used to calibrate the MVCT numbers in terms of electron density. The treatment plan parameters are used to recalculate the dose distribution in the MVCT image. The whole chain, from initial kVCT to final MVCT based dose recalculation was then applied to a rigid thorax phantom (CIRS Model 002LFC). The recalculation technique is based on the intended delivery and recalculation of the dose distribution in an MVCT image of a rigid phantom should result in a dose distribution identical to the planned dose distributions. This is tested and differences between the planned and recalculated dose volume histograms are reported. The prediction of dosimetric distortions caused by anatomical deformations is tested next. Several plans were delivered onto a deformed phantom anatomy. Recalculated point doses were compared with measurements. **Results**: In the four rigid phantom plans tested, the recalculated D_{95} for the target volumes agreed with the D_{95} from the planning kVCT to within 0.5 %. The measured change in point dose due to deformation of the phantom agreed with the recalculated change on average to within 0.5 %. **Conclusion**: The recalculation of tomotherapy plans on MVCT images is reliable and accurate. Changes in the patient dosimetry due to deformation can be determined using this technique**. Conflict of Interest:** Three of the co-authors are employees of TomoTherapy, Inc.

SU-FF-T-325

TVLs for Co-60 and 4, 6, 10, 15 and 18 MV X-Rays in Concrete for Beams of Cone Angle Between 0° and 14° Calculated by Monte Carlo

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Purpose: IMRT is becoming an increasingly important radiation therapy modality. For a linac dedicated to IMRT-based therapy, the shielding parameters would differ from those for one treating with conventional techniques. Published tenth value layers (TVLs) for shielding materials are for broad beam transmission and are therefore too conservative for these very small fields. Thus, a linac room designed exclusively for IMRT use would require lower TVLs for determining the required wall thicknesses for the primary barriers and would need narrower barrier widths. **Method and Materials:** The attenuation of ^{60}Co gamma ray and photons of 4, 6, 10, 15, and 18 MV x-ray beams by concrete has been studied using the Monte Carlo technique for beams of different half-opening angles between 0° and 14°. TVLs were determined to the 3rd TVL in each case. Transmission factors were calculated at distances of 30, 100 and 200 cm from the exterior wall of the concrete barrier **Results:** The transmission plots at 30 cm show the effect of build-up (BU) for angles >3° for all megavoltage beams. However, at 100, and 200 cm the build-up effect is greatly lessened because little of the scattered radiation from the barrier reaches the detector. For 100 cm, BU occurs for angles >9° and for 200 cm only for the largest angle. For Co60, there is BU for all angles at 30 and 100 cm and at 200 cm for angles >3°. The 1st, 2nd and 3rd TVLs all decrease with decreasing angle, the greatest drop being for the 1st TVL. When normalized to the TVL at 14°, the first TVL is almost independent of energy with values at 0° of 0.53±0.02 (30 cm), 0.59±0.01 (100 cm) and 0.67±0.02 (200 cm). **Conclusion:** TVLs for small IMRT fields are, as expected, substantially lowetr than those for large fields.

SU-FF-T-326

Application of the Pencil-Beam Redefinition Algorithm to Electron Arc Therapy

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Purpose: A dose algorithm suitable for electron arc therapy is not available on existing commercial treatment planning systems. This project investigated the potential for simulating an electron arc therapy beam by summing (1° angular steps) fixed-beam dose distributions calculated using the pencil-beam redefinition algorithm (PBRA). **Method and Materials:** Similar to the Hogstrom pencil-beam algorithm (PBA), the PBRA was commissioned for fixed beam geometries typical of electron arc therapy. The PBRA was constrained to calculate dose output for fixed beams as a function of field width and SSD. For arced beams, a small width correction was incorporated to conserve integral dose. Resulting arced beam calculations of dose output and mid-arc depth dose were evaluated by comparing to data measured using cylindrical water phantoms (ρ=12, 15 cm). Calculated 2D relative dose distributions in the plane of rotation were evaluated using film dosimetry in a polystyrene cylindrical phantom (ρ=13.5 cm). A wide range of treatment parameter combinations was investigated — three field sizes, three radii of curvature, and multiple arc angles at 10 and 15 MeV. **Results:** For arced beams, the maximum difference between PBRA-calculated and measured dose output at mid-arc was 2%. Along mid arc, the maximum dose difference in low dose-gradient regions was 3.4%, and the maximum distance to agreement (DTA) of dose values in high dose-gradient regions was 2.2 mm. Away from mid-arc, the maximum dose difference was 2%, and the maximum DTA was 1.2 mm. **Conclusion:** Results showed that the PBRA summation method can calculate dose in homogeneous phantoms within 3.4%. Since PBRA calculations in patients have been shown to be within 4% by Boyd et al., this method should be suitably accurate for use with electron arc therapy patients. User experience with the PBA and ease of PBRA beam commissioning make the PBRA attractive for this application.

SU-FF-T-327

Comparison of Characteristics of Electron Beams Generated by Siemens and Varian Linear Accelerators

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Purpose: To compare the electron beam data for Siemens and Varian accelerators. **Method and Materials:** Beam data for the electron beams for at least 4 linear accelerators are compared in seven categories: (1) percent depth dose for open beam and small circular cutouts, (3) phantom scatter factor, (4) head scatter factor as a function of cone size and SSD, (5) cone factors, (6) distance factor and (7) virtual source position. **Results:** PDD for broad beams is in good agreement among all accelerators. However, PDD for small circular cutouts of the two Siemens Oncor accelerators are different from the other accelerators with their mean energy shifted by 2 MeV. The phantom scatter factor, defined as the ratio of blocking factor in water at reference depth and head scatter factor in air, for the same cone size and radius, is a function of radius and nominal electron energy only, regardless of linac makers with a maximum and standard deviation of 10% (for the smallest cutout of 1cm) and 2.3%, respectively. The head scatter factor *H* is defined as the ratio of in-air

energy fluence between circular cutout with radius *r* and open cone for the same cone size and source-to-detector distance. The renormalized *H* is a function of electron energy and cutout radius. The cone factor for all energies, among all accelerators agreed within 1.9% among the Varian accelerators and 1.7% within the Siemens accelerators. The distance factors varied up to 10% for the smallest energy (6e) and up to 3.4% for the 21e. The virtual position varied by 3.8cm and 6.5cm for the Siemens and Varian accelerators, respectively. **Conclusion:** Accelerators from the same manufacturer, with the same nominal energy, can be treated as "identical" for conventional treatment except for small circular cutouts and large SSDs, where variations of 10% are observed.

SU-FF-T-328

Dosimetry of (< 3 Cm Diameter) 6 MeV Circular Field Electron Beams for a Varian 21EX Linac

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Purpose: Small ($\leq$ 3 cm diameter-ϕ) 6 MeV electron beam circular fields present complex dosimetry. This work provides absorbed dose rates in water at d_{max}, percentage depth doses (PDD), profile coverages, penumbra widths, uniformity and homogeneity indices for these fields for clinical treatments. **Method and Materials:** Circular (2 cm to 3 cm in 0.2 cm diameter increment) cerrobend cutouts were mounted in 6-cm x 6-cm cone. Central-axis depth-ionizations were measured with NACP parallel-plate ionization chamber in a solid water phantom. PDD were obtained using the TG-51 protocol. Cross-beam profiles at d_{max} of each cutout were measured with XV film in solid water phantom. Absorbed dose rates in water were determined as the ratio of maximum central-axis absorbed doses for each cutout, corrected for TG-51 parameters, to that of the 10-cm x 10-cm reference field. **Results:** As cutout ϕ decreases, the build-up portions of the PDD curves shift toward the phantom surface, and the d_{max} decrease from 1.2 cm to 0.6 cm. The dose gradient, G_o, an ICRU 35 measure of the steepness of the descending portion of the PDD, decreases from 2 to 1.5, but the practical ranges, R_p, remain constant. The absorbed dose rate decreases linearly with decreasing ϕ, but surface absorbed dose remains constant. 90% profile coverages (= width of 90% over cutout ϕ at d_{max}, 55%, and 80% coverages, 72%; homogeneity coefficients, 0.70, and the uniformity indices, 0.53 remain reasonably constant. The 80-20% penumbra to diameter ratios increase from 0.52 to 0.62 as diameter decreases. **Conclusion:** These data for $\leq$ 3 cm diameter circular fields facilitate routine clinical treatments. The absorbed dose rates and other data for small cutouts can be quickly obtained for patient treatments rather than performing measurements for individual patients.

SU-FF-T-329

Enhancing Magnetically Collimated Electron Beams for Breast Cancer Treatments

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Purpose: To develop magnetically collimated electron beams and to study their feasibilities for breast tumor bed irradiations. **Method and Materials:** We constructed an enhanced magnetic collimator with a beam aperture of 5.5 cm from permanent magnets using high-density Neodymium-Fe compounds. The collimator is cylindrical in shape and can be mounted at the end of an electron cone. The magnetic field is symmetrically aligned with the beam axis. The central axis of the magnetic field was calculated via finite element analyses and validated with Hall probe measurements. To implement magnetically collimated electrons for breast tumor bed irradiations, we measured and modeled the central axis depth doses and dose profiles of magnetically collimated electron beams on a flat water phantom. An empirical pencil-beam model was developed to calculate three-dimension dose distributions of magnetically collimated electron beams in CT studies. We implemented the dose model for breast tumor bed treatment cases. **Results:** Based on the dose distributions of the fixed and the arc beams of magnetically collimated electrons on the flat water phantom, the entrance dose is significantly lower than the conventional electrons (< 30% of the maximum dose). When treating the breast tumor bed, conformal dose distributions to the tumor volume are achieved with magnetically collimated electrons in contrast to single enface beam dose distributions. Isodose surface such as 90% of the maximum dose can be used to fully cover a target volume at depth. **Conclusion:** It is feasible to produce magnetically collimated electron beams with appropriate beam apertures. Conformal dose distributions from magnetically collimated electrons potentially create new regimens for breast tumor bed treatments.

SU-FF-T-330

Modeling Skin Collimation Using Electron Pencil-Beam Redefinition Algorithm

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Purpose: To modify the pencil-beam redefinition algorithm (PBRA) to model skin collimation and to verify that the modified PBRA can accurately calculate dose in the presence of skin collimation for both electron fixed and arced beams. **Method and Materials:** The PBRA continuously redefines pencil beams at equally spaced depth. For pencil beam pixels fully (partially) shielded by skin collimation further propagation of all (a portion) of the pencil beam is terminated. The accuracy of the modified PBRA for skin collimation (10-mm thick lead) was verified at 10 and 15 MeV. Fixed beam measurements were performed using a scanning diode detector in water: air gap is 32 cm, field size is 20x6 cm^2, and skin collimation is at +5.0 cm. Arced beam measurements were performed in a cylindrical, plastic phantom (ρ=13.5 cm) using film dosimetry: arc angle is $\pm$ 45º, skin collimation edge is at $\pm$ 30º, and field size is 5x20 cm^2. **Results:** *Fixed beam:* For 10 MeV, the calculations and measurements agreed within 2% in the low dose-gradient region (Dose>90% and Dose <10%) and within 2 mm distance to agreement (DTA) in the high dose-gradient region (10%<Dose<90%). For 15 MeV, calculations and measurements agreed within 5% in the low dose-gradient region and within 2 mm DTA in the high dose-gradient region. Differences from 3-5%, limited to a small volume distal to and just inside the skin collimation edge, were due to the modified PBRA not modeling scatter from the skin collimation. *Arced beam:* For both energies, the calculations and measurements agreed within 2% in the low dose-gradient region and within 1 mm DTA in the high dose-gradient region. **Conclusion:** Results showed that the PBRA is easily modified to include skin collimation and that it can calculate dose in a water or plastic phantom sufficiently accurately for clinical use.

SU-FF-T-331

Use of Photon IMRT Fields to Sharpen the Penumbra of Electron Fields Shaped with Photon MLC

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Purpose: Current electron beam therapy requires the production of custom lead cutouts in close proximity to the patient to minimize beam penumbra. This study investigated the use of a photon multi-leaf collimator (MLC) to collimate the electron beam and to improve its beam penumbra using photon IMRT fields. **Method and Materials:** Beam parameters were first measured for 9 and 12 MeV electron beams shaped by a Millenium MLC from a Varian 2100CD linear accelerator. The data was used to commission electron MLC beams in a commercial treatment planning system (Theraplan Plus, Nucletron). A semi-empirical method of creating the photon IMRT fields to reduce the penumbra was developed. Film dosimetry was used to compare plan predictions with the measurements of the electron/photon beam delivery. **Results:** We are able to model the MLC shaped electron beam with Theraplan plus reasonably well. By combining the penumbra reduction IMRT photons to the MLC shaped electron field, using Theraplan Plus, we obtained similar 50%-95% penumbra values compared to a cut-out shaped electron field alone, for several field sizes. Film dosimetry verified that the treatment field profile was similar to the Theraplan Plus prediction. This convenience of using the MLC to shape an electron beam does have significant drawbacks; as there is still a large increase in the lateral spread of the electron beam due to the increased source-to-surface distance. Secondly, the IMRT photon beam will add significantly to the dose at depth in the penumbra of the electron beam, which would have to be taken into account when irradiating near critical structures. **Conclusion:** Electron beams can be conveniently

collimated with photon MLC. The large beam penumbra for the electron MLC field can be reduced with IMRT photon fields to obtain dose profiles similar to those by cut-out shaped electron beams for the dose above 50%.

SU-FF-T-332

3D MRI-Based Tumor Delineation of Ocular Melanoma and Its Comparison with Conventional Techniques

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Purpose: The aim of this study was to compare the delineation of the tumor volume for ocular melanoma on high-resolution 3D T2-weighted fast spin echo MRI images with conventional techniques of A- and B-scan ultrasound, transcleral-illumination and placement of tantalum markers around tumor base. **Method and Materials:** High-resolution 3D T2-weighted fast spin echo (3D FSE) MRI scans were obtained for 50 consecutive ocular melanoma patients using a 1.5 T MRI in a standard head coil. These patients were subsequently treated with proton beam therapy at the UC Davis Cyclotron. The tumor was delineated by placement of tantalum rings around the tumor periphery during surgery. The patients were planned using EYEPLAN software and the tumor volumes were obtained. For analysis, the tumors were divided on tumor height and basal diameter. In order to assess the impact of high-resolution 3D T2 FSE MRI, the tumor volumes were outlined on the MRI scans by two independent observers and the tumor volumes calculated for each patient.
Results: 12% of 50 patients with tumor heights ≤3 mm were not visible on 3D MRI images. A small intra-observer variation with a mean of (–0.5±4)% was seen in tumor volumes delineated by 3D T2 FSE MR images. The mean variation of tumor volume measurements between MRI scan to EYEPLAN was (0.1 ± 2.5)%. The tumor shapes obtained from 3D MRI images were comparable to the tumor shapes obtained using EYEPLAN software. **Conclusion:** The demonstration of intraocular tumor volumes with the high-resolution 3D FSE MRI is excellent and provides additional information on tumor shape. We found a high degree of accuracy for tumor volumes with direct MRI volumetric measurements in uveal melanoma patients. The MRI scan provided shape information on the tumor, which was comparable with the shape data obtained from EYEPLAN software.

SU-FF-T-333

A Fourier Analysis of the Dose Grid Resolution Requirement in Proton Therapy IMRT Fluence-Map Optimization

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Purpose: We determine the minimum spatial sampling frequency required for proton beam dose computation so that the accuracy is guaranteed in the sampling phase and superfluous computational work is avoided. Our work is based on a previous analysis of photon beam IMRT resolution and we extend the work for arbitrary rotations of the beam about the dose grid. The accuracy criterion of the sampling is set up such that the dose distribution can be reconstructed from the sample within a specified error. **Method and Materials:** Fourier analysis and the Nyquist-Shannon Sampling Theorem are employed in the analysis. By the distributive property of the Fourier transform, the analysis can be done with a single proton beamlet in lieu of a composite beam. The beamlet was modeled as a 3D analytical dose function of an infinitesimal and mono-energetic proton beam in water. Fourier transforms of the dose function were carried out analytically in 3D for arbitrary orientations of the beam with respect to the dose grid. The Nyquist-Shannon Sampling Theorem was used to judge the minimal sampling resolution required for a specified error. Since the steepness of a proton beam is known to depend on its range, due to multiple Coulomb scattering, the resolution was determined as a function of radiological depth. **Results:** For proton beams with ranges from 3 to 30 cm, sampling resolutions from 0.8 to 8 mm are required for a worst case 2% error, and a near linear relation between range and required resolution was observed. The resolution requirement did not significantly change for small angulations with respect to the grid. **Conclusion:** Accurate proton dose computation can be performed with millimeter-sized voxels that increase in size with increasing range. We present adaptive voxel schemes to take advantage of this feature for proton IMRT.

SU-FF-T-334

Activation Induced by Proton Interactions in a Multileaf Collimator in Proton Therapy

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Purpose: The design of a computer-controlled multileaf collimator (MLC) for use in a proton radiotherapy beamline requires investigation of issues of neutron and radioactive isotope production due to activation, which result in an increase of dose to patients and personnel. **Method and Materials:** Materials such as tungsten (W), tungsten-copper (10%) alloy (WCu10), iron (Fe), low-carbon steel (LCS), medium-carbon steel (MCS), and brass have been studied to explore proton-induced radiation activation and generation of neutrons under proton bombardment of energy up to 250 MeV. Analysis was based on a wide variety of experimental and nuclear reaction simulation data. Neutrons generated will induce additional radioactivity in the MLC, in other materials in the treatment room, and will deposit undesirable dose in the patient. The size and cost of the materials need to be considered as well.
Results: The probability of neutron production per 25 MeV energy interval of incident protons has been calculated for the selected materials as the proton stop. Furthermore, the probability for generation of radioactive products has been studied. The predominate radioactive nuclides with half-lives greater than 1 hour generated in three materials were as follows. For Fe: $_{27}Co^{58,57,56,55}$,$_{26}Fe^{55,53,52}$, $_{24}Cr^{51,58}$, $_{25}Mn^{54,52,51}$, and $_{23}V^{49,48,47}$. For brass: $_{29}Cu^{64,62,61}$, $_{30}Zn^{65,63,62}$, $_{31}Ga^{68,67,66,65,64}$, $_{27}Co^{60,58}$, $_{82}Pb^{203,202,201}$, $_{83}Bi^{203,204,205,206,207}$, $_{81}Tl^{204,201}$, $_{80}Hg^{203}$. For W: $_{74}W^{185,181,179,178}$, $_{75}Re^{186,184,183,182,181}$, $_{73}Ta^{183,182,179,177,176}$, $_{72}Hf^{184,181,179,178,177,175,172,173}$. In terms of neutron production W has three times higher neutron multiplicity compared to Fe; however, W density is also 2.5 times as high to Fe and because of the higher atomic number may have better self-shielding properties. **Conclusion:** These results are being used to select an optimal material, not only for an MLC, but also for other patient devices used in proton therapy.

SU-FF-T-335

Analytical Calculation of Spread-Out-Bragg-Peak Distributions for Laser-Accelerated Proton Beams

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Purpose: To present a fast and robust analytical method for spread-out-Bragg-peak dose distribution calculation for energy and intensity modulated radiation therapy using laser-accelerated protons. **Method and Materials:** A simple analytical calculation of the proton energy spectrum needed to produce a spread-out-Bragg-peak (SOBP) is obtained through the solution to the Boltzmänn kinetic equation. Since the SOBP is realized through the superposition of discrete rather than continuous arrangement of Bragg peaks, the weighting function $W_i(E_i,\Delta,\delta)$ needed to obtain SOBP depth-dose distribution using laser-accelerated protons is calculated through the integration of the continuous distribution function over the finite energy sampling size δ and subsequent expansion of the resulting function into the series of Gaussian distributions of finite width Δ. There exists a correlation between the energy width Δ on one hand and the sampling size δ on the other. A variety of different δ/Δ ratios were considered and an optimal value for this parameter is found. **Results:** The obtained expression for the weights depends only on the characteristic energy E_i of the given proton beam, the width of its energy spread Δ and the energy sampling size δ As an example, we show that for the sampling size δ=5 MeV, a superposition of proton beams with the maximum energy spread Δ=3.5 MeV is needed. Proton beams with larger energy spreads will generate the resulting weight distribution, which will significantly deviate from that obtained by the integration of the energy spectrum (derived from the solution to the Boltzmänn kinetic equation) over the sampling interval δ. **Conclusion:** This work is a part of inverse treatment planning system for patient dose calculation using laser-accelerated protons. It presents a fast SOBP dose calculation method for each individual beamlet. It also provides a basis for a physical way of energy modulation implementation in laser-proton accelerator.

SU-FF-T-336

Characterization of the Proton Beam of the Centre De Protontherapie D'Orsay with An On Line 2D Parallel Plate Ionization Chamber

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Purpose: To monitor and to evaluate on line the parameters of the proton beam at the Centre de Protontherapie d' Orsay (CPO) in France. **Method and Materials:** A parallel plate ionization chamber has been developed in the University and INFN of Torino in collaboration with the CPO; the detector has a sensitive area of 160 x 160 mm^2, with the anode segmented in 1024 square pixels arranged in a matrix of 32 x 32; each pixel has an area of 5 x 5 mm^2 and a pitch of 5.1 mm. The detector has a maximum rate transfer of 5 MHz and the reading of the entire chamber can be done at a frequency of some kHz without dead time.
At the Centre de Protontherapie d' Orsay (CPO) a synchrocyclotron is used for the treatment of eye melanoma since September 1991 and for brain tumors since 1993. The dose delivery system is passive scattering and the proton energy delivered by the synchro-cyclotron is 200 MeV which allows the treatment of lesions up to 22 cm deep in water.
The pixel chamber has been placed along the CPO beam line to monitor the beam shape and to measure the stability and reproducibility of the delivery system. **Results:** Background measurements have been made to evaluate the pixel chamber noise; a procedure for the calibration of the detector has been beam applied that makes use of film measurements. Profiles and 2D dose distributions have been studied to see the uniformity of the delivery system and the reproducibility of the measures has been tested. **Conclusion:** A pixel chamber developed in Torino has been placed on the proton CPO beam line. This detector allows a fast, accurate and non-intrusive 2D diagnosis of the beam both on- and off -line.

SU-FF-T-337

Clinical Implementation of Proton Monte Carlo Dose Calculation

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Purpose: Clinical use of Monte Carlo dose calculation to support routine treatment planning and delivery at the Northeast Proton Therapy Center. **Method and Materials:** The Monte Carlo code GEANT4 was used to model the treatment heads. More than 1000 objects were considered in the geometry. This includes a time dependent simulation of the modulator wheel (broad beam modulation) and the magnetic field settings (beam scanning). The code was benchmarked against phantom measurements. Further, the capability of using CT data information was implemented in GEANT4. Different Hounsfield unit to material conversion methods were tested. The standard GEANT4 tracking algorithm was modified to allow time-efficient dose calculation. A software link of the Monte Carlo dose engine to the patient database and the commercial planning system was established. **Results:** The setup for Monte Carlo dose calculation is automated via a user interface. Information from the commercial treatment planning system and the treatment machine control software is imported to generate Monte Carlo input files. Dose calculations have been performed for radiosurgery and for breast, paranasal sinus, spine, and lung malignancies. Monte Carlo dose distributions can be imported into the planning system for analysis. Differences to the planning program could be identified. Due to the detailed model of the treatment head, Monte Carlo is also being used for absolute dosimetry. The reading of the segmented parallel plate ionization chamber in the treatment head was simulated with 1.4 % accuracy. Output factors can thus be simulated using the patient geometry. **Conclusion:** Proton Monte Carlo dose calculation for treatment planning support can be efficiently done using GEANT4 based software. Re-calculated plans can be used for decision making in the planning process. Simulated output factors allow the use of Monte Carlo for absolute dosimetry. This is the first clinically implemented complete Monte Carlo for proton therapy.

SU-FF-T-338

Comparison Between Proton and Neutron Dose Distributions From Single-Scattering and Dual-Scattering Systems in Ocular Proton Therapy

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Purpose: Typically, ocular proton treatment nozzles use a single-scattering (SS) flattening filter design to achieve lateral spreading of a raw pencil-beam to create a flat field. This approach has the advantage of simplicity but at the cost of proton efficiency, η. It is expected, though never demonstrated, that a more efficient, dual-scattering (DS) flattening filter design may possess several advantages. **Method and Materials:** A proton nozzle with the SS filter design was modeled in Monte Carlo (MC) radiation transport software. Simulations of this nozzle provided in-field proton absorbed dose distributions in water, *D*, and the neutron dose equivalent values, *H*, outside of the field, which were subsequently benchmarked to published measurements. Then, a proposed nozzle was modeled that uses a DS filter design. Simulations of the SS and DS nozzles were conducted to investigate differences in several figures-of-merit including the distal 80%-20% falloff $l_{D80\text{-}20}$ and neutron dose equivalence per therapy Gray (*H/D*) distributions. Other figures-of-merit presented will include the field uniformity *U*, therapeutic dose rate *D*dot, and the 80-20% lateral penumbral width $l_{L80\text{-}20}$. **Results:** The simulations and measurements of the proton absorbed dose distributions from the SS nozzle agreed to within 2% or 0.1 mm. The shape of the measured and simulated *H/D* values as a function of distance from isocenter perpendicular to the beam agreed within 3%. The distal falloff width was expectedly narrower from the DS nozzle by 2.5 mm. The simulations revealed that the DS design yields substantially lower *H/D* values (between 0.3-0.6 times the SS values). This is partially attributed to the DS design's increased peak dose per proton. **Conclusion:** The DS flattening filter design may offer clinical advantages when compared to the SS filter design, including a sharper distal falloff, *D*dot, and decreased *H/D* values.

SU-FF-T-339

Comparison of Pencil Beam Algorithm and Monte Carlo Dose Calculation for Proton Therapy of Paranasal Sinus Cancer

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Purpose: To verify the accuracy of the pencil beam algorithm implemented in the FOCUS (CMS) proton treatment planning program with a GEANT4 based Monte Carlo code. Due to the presence of large air cavities and tissue inhomogeneities, paranasal sinus (PNS) cancer brings challenges to radiotherapy treatment planning. **Method and Materials:** GEANT4 based Monte Carlo methods have been used to simulate multiple PNS cases for the purpose of examining the reliability of the pencil beam algorithm. To guarantee the accuracy of the results by Monte Carlo, the proton treatment nozzle and the patient geometry were modeled in great details, and all related physics processes were included. Different conversion methods for assigning material properties to different Hounsfield units were applied and tested. Electron densities in the Monte Carlo were normalized to the ones used by FOCUS. **Results:** Monte Carlo and FOCUS present a very good agreement in dose distributions, except for in low-density air cavities. Monte Carlo reports a significantly lower dose in air than FOCUS, primarily due to a much lower mass stopping power in air than in water. Air cavities, included accidentally in planning contours can cause significant errors in DVHs. With air regions excluded, the DVHs for target structures of Monte Carlo and FOCUS show a good agreement. Differences could be seen in low dose regions and close to material interfaces. However, they are insignificant in most cases. Important, in particular for proton therapy with sharp dose fall-offs, is the fact that the beam ranges agree very well. **Conclusion:** This work indicates that the pencil beam algorithm in FOCUS (CMS) is reliable for cases involving large air cavities and bony tissues. However, air cavities should not be included when volumes are drawn for treatment planning.

SU-FF-T-340

Effect of Marker Implants On Dose Distribution in Proton Therapy

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Purpose: To determine whether the dose perturbations caused by implanted markers in or near the mobile tumors have significant impact on the dose distributions, particularly by creating hot or cold spots behind the markers. **Method and Materials:** A preliminary dose-depth distribution measurement with 200 MeV protons has been performed at the Proton Medical Research Center of the University of Tsukuba. The effective-source size was approximately 4 cm, the source-to-surface distance (SSD) was 250 cm and the Spread Out Bragg Peak (SOBP) modulation range was 5 cm, between 15 cm and 20 cm depths. A cylindrical Gold marker with 0.3 cm length and 0.12 cm radius has been placed, both in horizontal mount and vertical mount, at 14 cm and 17 cm inside the water tank. The doses have been measured using a novel imaging plate technique. Analytical SOBP dose calculations have been performed in the y = 0 plane, using □z depth integration steps of 0.04 cm and □x cross-field lateral steps of 0.01 cm. **Results:** Analytical calculations showed that the presence of the markers modify quite significantly the Central Axis (CAX) dose distributions of single Bragg peaks. However, this dose perturbation is washed out almost entirely when employing the SOBP technique using multiple modulated Bragg peaks. In such case, the CAX dose increases behind the markers by less than 1% and decreases by less then 3% at the distal end of the SOBP plateau. The experimental measurement of the CAX dose distribution did not observe a significant effect, which confirms the theoretical prediction. **Conclusion:** This work indicates that it should be safe to use small Gold markers in the proton therapy of mobile tumors employing SOBP techniques. The investigation will be continued using various marker sizes and materials of clinical interest, different proton energies and an ionization chamber.

SU-FF-T-341

Energy Distributions of Proton Interactions in MCNPX and GEANT4 Codes Using a Slab Target

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Purpose: Nuclear interactions for proton radiation therapy can be simulated by different Monet Carlo codes. In this study, the energy distributions of secondary particles generated from proton nuclear interactions by GEANT4 and MCNPX are compared. **Method and Materials:** Proton ranges were first calculated for proton energies from 70 to 250 MeV using these two codes respectively. A 1-cm thick water (or brass) slab was placed in the vacuum as a target of nuclear interaction. A point-like proton source was emitted in a single direction perpendicularly to the slab. The detector on the other side of the slab recorded the energy distributions of particles generated in nuclear interactions including neutrons, protons, alpha particles. The simulations were repeated for both slab materials at different energies between 100 MeV and 250 MeV. **Results and Discussions:** We first compared the calculated ranges with the proton CSDA data from NIST. GEANT4 always gives shorter ranges than the CSDA, while MCNPX only does so for energies higher than 100 MeV. We next studied the energy distribution of the particles generated in nuclear interactions. The proton distributions are quite similar for 150 MeV incident energy case. MCNPX predicts neutrons with, on average, higher energies that GEANT4. As for alphas, the statistical uncertainties are too high (~30%) and the results are qualitative rather than quantitative. **Conclusion:** The results suggest that these two codes are in good agreement for proton distribution, although discrepancies in the average neutron energies are observed due to the different physical models

SU-FF-T-342

Evaluating a 2D Proton Spotscanning Profile

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Purpose: A quantitative analysis tool for the evaluation of 2-dimensional dose deposition profiles resulting from irradiation with scanned proton beams is presented. Analysis is performed by calculating a γ index originally proposed for use in intensity modulated photon therapy. **Method and Materials:** At the Proton Therapy Center in Houston, currently under construction, quality assurance of scanned proton beams will be carried out with a scintillation plate and a CCD camera. In the absence of beam, a 2-dimensional dose distribution is generated by superposition of Gaussian profiles. It is compared to a desired dose distribution derived from the treatment plan. The γ index was computed for various generated dose distributions using software written using LabVIEW® for the purpose of this study. The difference between the generated and the desired dose distributions consists in different weights being assigned to individual spots, variations in the spot shape (FWHM), and misalignments of individual spots. **Results:** For the investigated spot arrangement containing 121 spots uniformly distributed an o grid of 10x10 cm^2, nominal width σ = 8 mm, the method invalidates the treatment delivery for misplacements of the Gaussian beam spots larger than 2 mm, variations on spot weight larger than 12%, and variations in the spot shape larger than 16%. **Conclusion:** The "gamma method" shows promise as a quality assurance tool for spot scanned proton beam.

SU-FF-T-343

Focal Stereotactic Proton Irradiation: Micro CT Planning and Assessment by MR Spectroscopy

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Purpose: Develop focal stereotactic proton irradiation for accurate spatial localization (< 2mm) in the rodent brain. Planning and evaluation was performed using Micro-Computed Tomography (CT) and magnetic resonance spectroscopy (MRS). **Method and Materials:** Rodents were visualized using Micro-CT; the data was transferred to Optirad (proton treatment planning system) for planning the site of brain irradiation (20 Gy). After irradiation the animals were positioned for proton magnetic resonance spectroscopy (MRS) on a 4.7T imager. Acquisition conditions for metabolite assessment allowed complete relaxation between excitations. A 5 mm^3 voxel was placed at the irradiation site. Care was taken to avoid bone-tissue interfaces. The MRS data was collected into 2048 points (frequency resolution of 1.2 Hz/point), a relaxation delay of 4s and an echo time of 120ms. A water presupression pulse reduced the water peak below 1%. The MRS acquisition parameters were; a field of view of 5 cm, two acquisitions, a matrix size of 256 X 128 for a total imaging time of 8.5min. **Results:** At 12 hrs after focal irradiation, MRS revealed the presence of a lactate (Lac) peak that did not resolve during the course of the 5-day imaging series. In addition, the peak height of N-acetyl-aspartate (NAA) was reduced at 12 hrs compared to choline (Cho) and creatine (Cre) peaks. The NAA changes relative to Cho/Cre appeared to resolve over the 5 day time course. **Conclusion:** Focal stereotactic proton irradiation (<2mm) can be obtained when combined with CT and MRS. Validation of high dose focal irradiation by MRS suggested cellular injury as evidenced by a persistent lactate peak, indicative that cellular necrosis continues for at least five days . Transient neuronal injury was shown by reduced NAA/(Cho+Cre) at 12h with a partial recovery over the next five days. Histology was performed to further validate these findings.

SU-FF-T-344

Impact of Inter-Fractional Motion of the Anatomy On Prostate Proton Dose

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Purpose: The purpose of this study is to determine whether the inter-fractional motion of the anatomy has a more significant impact on proton dose distributions compared to IMRT dose distributions. A secondary objective is to evaluate the impact of CTV-to-PTV margins on plans for protons produced with the double scattering technique. **Method and Materials:** Repeat CT scans of prostate patients acquired with a CT-on-Rails were used for this study. First, proton and IMRT plans were designed using (1) the CTV-to-PTV margin standard at our institution (normally 8 mm except at the rectum-prostate interface, where it is 5.8 mm) and (2) a small uniform margin (3mm). The proton and IMRT plans were then applied to 8 daily CT images aligned either to skin marks or the center of

prostate. The doses for the 8 daily CT images were recalculated using the same beam configurations (aperture, compensators, gantry angles, Monitor Units etc). **Results:** For proton plans, a 3mm margin appears to be adequate for tumor coverage even when a conventional skin mark alignment technique is used. The proton plans with 3mm margins lead to nearly the same coverage as in the IMRT plans with standard margins. For prostate center of volume-based alignment, this coverage was 98.6% for protons vs. % 98.1 for IMRT and 96.6% vs. 96.3% for skin marks-based alignment. **Conclusion:** With the double scattering technique, the dose distribution from the proton plan is not very sensitive to the daily variation of the patient anatomy as compared to IMRT plans. The 3 mm CTV-to-PTV margin is acceptable for proton plans but not for IMRT plans for both alignment methods. The preliminary data show that the CTV-to-PTV margin can be reduced to 3mm if we use daily image guided set-up.

SU-FF-T-345

Measured Output Factors for Range-Modulated Spread-Out Bragg Peak Proton Beams

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Purpose: The magnitude and the trend of variation of the output factor (OF) for range-modulated spread-out Bragg peak (SOBP) proton beams are investigated as a function of the range, modulated SOBP width and field size. **Method and Materials:** The proton delivery system of the fix horizontal beam line (FHBL) used at the Midwest Proton Radiotherapy Institute (MPRI) has been calibrated to give an output of 1.0 ± 1.0% cGy/MU at a reference condition. For field that deviates from reference is measured at center of the SOBP at the room "isocenter". The OFs were measured with the fields that varied with range, SOBP width and size. Pristine curves for the various field sizes were also measured to study observed variation in the measured output factors. **Results and Conclusion:** For a field size of 10 cm in diameter, the OFs at the middle of a 10 cm SOBP vary 40% between 14 and 27 cm ranges in water and a similar trend with range is observed for a 6 cm SOBP. The OFs of a 17 cm range vary 60% between SOBP widths of 2.6 and 12.4 cm and a similar trend in SOBP width is observed for other ranges. For field sizes 2-10 cm diameters and a 10cm SOBP, 5% and 20% variations were observed for ranges of 12 and 27 cm, respectively. The trend in field size differs largely between different ranges. In theory, the trend in field size can be calculated from the ratios of Bragg-peak to entrance doses from measured pristine curves. However, the calculated output factors are significantly lower than the measured one for a small field size. Although the output factor can not be predicted theoretically, these measured output factors can be modeled analytically.

SU-FF-T-346

Monte-Carlo Investigation of Proton-Generated Radioactivity in a Multileaf Collimator for a Proton Therapy Facility

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Purpose: The requirements for a multi-leaf collimator (MLC) for a proton therapy facility include the neutrons and radioactive products generated by proton interactions in the collimator material. The range of protons decreases with increasing density of the leaf material, which suggests fabricating the MLC with a high density material to keep the length short. However, the rate of nuclear spallation events whereby particles such as n, ^{2}H, ^{3}H and α are ejected depends on the target nucleus. **Method and Materials:** The GEANT4 Monte-Code code was used to determine, per incident proton, the rate of these reactions as a function of proton energy in tungsten, iron and brass. In addition, the radioactive daughter products resulting from these interactions were evaluated. **Results:** Neutron production per incident 250 MeV proton on a leaf 1 cm^{2} in cross-sectional area and 10 cm in length was found to be 0.94, 1.27 and 1.75 for iron, brass and tungsten respectively. Decreasing the leaf thickness of W from 10 cm to 5 cm, which is still greater than the range of a 250 MeV proton in W, did not change the neutron production significantly (<3%) suggesting that the majority of neutrons were produced by the proton interaction and not by the interactions of the secondary neutrons. The mean neutron energy was between 15-17 MeV in all three materials, and 95% of the neutrons produced had energy less than 60 MeV. The yield of ^{2}H and ^{3}H particles, generated per incident 250 MeV proton was 0.178 and 0.096 respectively for all three metals. Alpha particles generated per incident 250 MeV proton were 0.08, 0.092 and 0.124 for Fe, brass, and W respectively**.** **Conclusion:** The production rates of secondary particles and radioactive isotopes within the MLC, and the associated radiation safety concerns, have been explored using GEANT4.

SU-FF-T-347

Proton Dose Calculation Using Monte-Carlo-Validated Pencil Beam Database for KonRad Treatment Planning System

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Purpose: To improve quality and reliability of dose calculation based on pencil beam model, in treatment planning for intensity-modulated proton therapy (IMPT). **Method and Materials:** Inverse treatment planning system KonRad (developed at DKFZ Heidelberg, commercially distributed by Siemens) employs pencil beam algorithm for dose calculation. Dose distributions for proton energies of 60 through 250 MeV, and various widths of the beam were precalculated using a Monte Carlo code, based on GEANT4. The results, which included description of depth dose profiles and beam broadening in tissue due to multiple Coulomb scattering, were stored in the pencil beam database. The updated database was used to optimize IMPT treatment plans. Dose calculation, assuming delivery of optimized beam intensity patterns by continuous magnetic scanning, was repeated with Monte Carlo, and the results were then compared to those obtained with KonRad pencil-beam-based calculation. **Results:** Monte Carlo calculation was in good agreement with a set of proton depth dose measurements taken in a water phantom. With the nuclear interactions "turned off", Monte Carlo description of multiple Coulomb scattering agreed well with the theoretical model. Nuclear interactions contributed substantially to broadening of the dose distribution for higher-energy (over 150 MeV) proton beams, mainly at relatively shallow depths. Fitting both nuclear and non-nuclear contributions to a single Gaussian, for the database, produced a negligible systematic error in KonRad dose calculation at shallow depths (less than 0.3\% of the peak dose). For sample plans, Monte Carlo and KonRad dose distributions (point doses) agreed to within 5 percent of the target prescription, except in the lung (non-cancerous) tissue, where disagreement of up to 15% was observed. **Conclusion:** The use of Monte Carlo data in parametrization of pencil beam kernels improved the precision of proton dose calculation without increasing the calculation time.

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SU-FF-T-348

Study of Truncated Cone Filters Using GEANT4

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Purpose: A ridge filter has been used for proton therapy to form a spread-out Bragg peak (SOBP). As the SOBP width becomes larger and the distal falloff becomes smaller, more number of ridge elements is required for the ridge filter. Then extremity of the ridge filter becomes too sharp to machine for large SOBP widths. Since an aperture collimator shapes the proton beam, beam mixing by adjacent ridges is affected by scattering in the ridge elements in the peripheral region. Namely, the proximal part of the SOBP begins to fall at depth deeper than the expected depth. A purpose in this study is to achieve uniformities of both the SOBP and the lateral dose distribution by improving a conventional ridge filter. **Method and Materials:** We have designed a two-dimensional array of truncated cone filters (TCF) in honeycomb structure. Since extremity of the TCF is moderate compared with a conventional ridge filter (CRF), manufacturing the TCF is relatively easy. Thus the TCF enables selection of lighter material with smaller scattering effect. In this study, a CRF (aluminum alloy) and a TCF (Lucite) with a SOBP width of 60mm were designed for a 155MeV proton beam. We simulated dose distribution in water for a therapeutic beam with GEANT4 to investigate the influence of both ridge filters. **Results:** While a few% dose decrease is observed in the proximal

part of the SOBP region for the CRF, the dose distribution is more uniform in entire of SOBP region for the TCF. **Conclusion:** We designed a two-dimensional array of TCF. It is easier to machine the TCF for SOBP filters with large SOBP widths especially for low-energy protons. Overall dose uniformity of the SOBP region in the TCF was improved as compared with the CRF.

SU-FF-T-349

Validation of DSAR Algorithm for Intensity Modulated Neutron Radiotherapy

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Purpose: To validate the differential scatter air ratio dose calculation algorithm for Intensity Modulated Neutron Radiotherapy (IMNRT). **Method and Materials:** Our current treatment planning system uses a differential Scatter Air Ratio (dSAR) technique to calculate neutron dose distributions from a d(48.5) + Be cyclotron. An empirical function was used to fit the profiles at different depths. Intensity modulated beams are delivered using the segmental MLC (sMLC) technique. Application of the dSAR method to small beam segments used for IMNRT has been investigated. Beam profiles for rectangular fields ranging from 2 x 2 cm^2 to 10 x 10 cm^2 were measured using a 0.3 cc TE chamber and compared to that predicted by the empirical profile function. This chamber has a diameter of 6 mm and a wall thickness of 2.5 mm. Point dose measurements using the dual ionization chamber technique and individual profile measurements were performed to validate the dose calculation accuracy for small irregular segments. **Results:** For field sizes ranging from 2 x 2 cm^2 to 10 x 10 cm^2, measured profiles agreed with the dSAR calculations to within 5% at 2.5 cm depth, and to within 3% at 10 cm depth, inside the field. The pdd's matched to within 2% of that calculated by the treatment planning system. For irregularly shaped segments, absolute point dose measurements matched to within 2% along the central axis and to within 3% for off-axis points. For some irregular segment profiles, large deviations were observed in the penumbral region, particularly at shallower depths. This was due primarily to partial volume effects resulting from the large diameter of the ionization chamber used for measuring these profiles. However, all measured profiles agreed with the calculated profiles to within 5% inside the segments. **Conclusions:** The dSAR dose calculation algorithm has been validated for IMNRT.

SU-FF-T-350

A Comparative Dosimetric Study of Three-Dimensional Conformal, Dynamic Conformal Arc, and Intensity Modulated Radiation Therapy for Brain Tumor Treatment

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Purpose: To investigate dosimetric differences among three-dimensional conformal (3D-CRT), dynamic conformal arc therapy (DCAT) and intensity modulated radiotherapy (IMRT) for brain tumor treatment for a broad range of brain tumor volumes and shapes in an effort to determine whether a preferred method can be identified based upon pre-treatment characteristics. **Method and Materials:** Fifteen patients treated with Novalis were selected. We performed 3D-CRT, DCAT and IMRT plans for all the cases. The beam numbers in 3D-CRT or IMRT plans were the same as the arc numbers in the DCAT plans, and the gantry angle of each beam in 3D-CRT or IMRT plans was the middle angle of each arc in the DCAT plans. The PTV margin was re-chosen as 1mm, and the specific prescription dose was re-set to 90% for all the plans. The target coverage at prescription dose ($TV_{90\%}$), conformity index (CI) and heterogeneity index (HI) were used to compare the different plans. $V_{50\%}$ and $V_{80\%}$ of the organs at risk (OAR) were also calculated. **Results:** For small brain tumors (PTV≤2cc), three dosimetric parameters had approximate values for both 3D-CRT and DCAT plans ($\overline{TV_{90\%}}$ ~93%, $\overline{CI}$ ~1.7, $\overline{HI}$ ~1.4). The CI for IMRT plans was high ($\overline{CI}$ =3). For medium brain tumors (2cc<PTV≤100cc), the three plans were competitive with each other. IMRT plans had higher CI and better $TV_{90\%}$ and HI. For large brain tumors (PTV≥100cc), IMRT plan had nearly perfect $TV_{90\%}$ and HI and the approximate CI values as those in both 3D-CRT and DCAT plans. **Conclusions:** DCAT is suitable for most cases in the treatment of brain tumors. For a small target, 3D-CRT is still useful, and IMRT is not recommended. For larger brain tumors, IMRT is superior to 3D-CRT, and very competitive in sparing critical structures near the target, especially for the treatment of a big brain tumor.

SU-FF-T-351

A Treatment Planning Study Comparing Whole Breast Radiotherapy Against Conformal, IMRT and Tomotherapy For Accelerated Partial Breast Irradiation

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Purpose: Conventional early breast cancer treatment consists of a lumpectomy followed by whole breast radiation therapy (WBRT). Accelerated partial breast irradiation (APBI) is a method to reduce the irradiation volume to the lumpectomy site plus appropriate margins and reduce treatment time from 5 weeks to 1 week. A radiotherapy treatment planning study was done using postoperative treatment planning CT scans of 15 patients with early breast cancer (T1, T2, N0) to compare four techniques for APBI. **Method and Materials:** Patients were placed in the supine positions and CT images were taken at three to four weeks after definitive breast surgery and patients were treated with WBRT. The CT data for these patients was used to compare four external beam techniques for APBI (small-field tangents, conformal radiotherapy, intensity-modulated radiation therapy and helical tomotherapy) with WBRT. Critical structures (heart, contra-lateral breast, uninvolved breast, lungs and skin) were contoured on the CT simulator software. The GTV was defined as the union of seroma volume and the volume bounded by the surgical clips. The CTV was defined with a 1.5-cm margin around the GTV, constrained to within 5 mm to the skin surface and within the ipsilateral breast volume. A 1cm expansion of the CTV used to create the PTV. Two types of dose homogeneity indices and a Conformity Index were used to evaluate the dose to the target. **Results:** All proposed APBI techniques delivered a significant increase in conformity index while maintaining homogeneity and not allowing for a significant increase in dose to critical structures compared with whole breast tangents. **Conclusion:** With increasing amounts of sophistication in the delivery of radiotherapy to the lumpectomy site an increase in the conformity index is observed with doses to critical structures that never exceed the whole breast case.

SU-FF-T-352

An Analytic Algorithm for Dose Calculation in An Inhomogeneous Medium

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Purpose: To develop an analytic algorithm for calculating dose distributions in a heterogeneous medium using density scaling of the scatter dose in a convolution model. **Method and Materials:** First, the dose in homogeneous medium was separated as primary and scatter dose. Second, primary and scaling doses were scaled. While scaling of the primary dose is straightforward, in this work we propose that scaling factor for scatter dose be expressed as the ratio of the kernel convolution within inhomogeneous medium to the one in homogeneous medium. With this scaled scatter dose, the total dose in the inhomogeneous medium was calculated in a challenging 3-D geometry of a 50 keV point source with a spherical inhomogeneity containing lung or bone tissues. The analytic calculations were compared with the Monte Carlo results using the PENELOPE code. **Results:** Compared to Monte Carlo results, both the magnitude and the slope of the dose in the lung material were precisely calculated within lung inhomogeneity, while for within bone inhomogeneity, the magnitude and tendency were correct but the slope had less reduction along the primary photon direction. The dose distributions in the areas surrounding the inhomogeneities were predicted within 5%. Compared to the existing superposition/convolution algorithm such as Collapsed Cone Convolution, this algorithm has a much simpler form and fewer requirements for the point kernels. **Conclusion:** The dose distribution in inhomogeneous media can be calculated with acceptable accuracy by using this extended scaling algorithm. The simple formulation and fewer requirements for the detailed point kernel will allow this algorithm for practical clinical application.

SU-FF-T-353

Clinic Implementation of Automated Planning for 3D-Conformal Therapy

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Purpose: We have implemented clinically an automated planning tool for 3DCRT that simultaneously optimizes the beam angles, beam weights, wedge angles, and wedge orientations. **Method and Materials:** An automated planning tool for 3DCRT has been developed that interfaces to the Pinnacle[3] treatment planning system through its hotscripts utilities. Pinnacle[3] is used for dose calculation, plan evaluation, and RT export. A commercial optimization software package (GAMS) is used for plan optimization. For each planning problem, the optimized beam angles and their weights were chosen from either 36 or 72 candidate beams along with their corresponding wedged fields. Because dose contributions from all candidate beams are needed for the optimization, the amount of data is very large. We developed a three-phases sampling technique to effectively handle the large data set and reduce the optimization time. **Results:** The tool has been applied to several cases including pancreas, head-and-neck, and lung patients. All planning parameters for a 3DCRT plan can be optimized within 20 minutes, and the optimized plans are comparable to those of experience dosimetrists. By using a three-phase approach, the optimization time can be reduced significantly. During initial angle selection phase, optimizations were performed on randomly selected subsets of the dose calculation points representing about 1% of the points. During the second phase, the gantry and wedge orientation can be obtained from the previous phase with about 10% of original data, and the weight of the selected gantry and wedge fields can be optimized with more data points in the final phase. **Conclusion:** We have developed an automated planning tool for 3DCRT. The tool has been evaluated using several treatment sites. Optimized plans can be obtained within 20 minutes and are comparable to those of experience dosimetrists.

SU-FF-T-354

Development of 3D Planning for Obese Patients Larger Than CT FOV Using PHILIPS Pinnacle 3 Treatment Planning System

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Purpose: To develop a methodology for development of 3D planning of obese patients larger than CT field of view (FOV) using PHILIPS Pinnacle[3] treatment planning system. **Material & Methods:** Obese patient larger than CT FOV was scanned on Siemens Emotion Duo CT simulator in two laterally shifted positions. The Patient had appropriate BBs (central and lateral CT markers) on the central plane. The patient was first positioned such that one side of the patient's contour is fully visible in the reconstructed image. Another similar data set was acquired by shifting the patient laterally. A new composite CT data set with a larger FOV was generated by mapping the left and right halves of the two data sets using the indigenously developed software. Typically the images were joined at a user selectable sagittal plane. In this way, it was possible to fuse the above image sets to makeup the full patient for target/structures delineation. A traditional 3D planning on Pinnacle3 was carried out. **Results:** An acceptable 3D plan data set was generated and dose distribution along with DRR was obtained using Pinnacle[3]. The DRRs were compared with AP and LAT simulation films and acceptable results were obtained. Similarly, the plan SSDs and depths were compared with data from patient setup with satisfactory results. **Conclusion:** A methodology has been developed, tested and implemented for the obese patients with larger CT FOV for 3D planning on Pinnacle[3]. Essentially using this method, the 50 cm diameter FOV limitation of our scanner has been increased to 70 cm FOV. This was useful for a few selected individual cases in our clinic. While the composite data set is dependent upon the accuracy of patient positioning, several improvements are planned for the future.

SU-FF-T-355

Effects of the Intravenous Contrast On Dose Distributions

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Purpose: To quantify the effects of the intravenous CT contrast media on the dosimetry for 3D conformal and IMRT Treatment Planning. **Method and Materials:** OPTIRAY 300 contrast agent (300 mg/ml organically bounded Iodine, Mallinckrodt Inc.) with the typical injection rates of 0.5 ml/sec for the brain tumor sites and 1.0 ml/sec for the abdomen tumor sites was used in our studies. Two CT data sets were acquired for each patient under study: one control CT set without the contrast, and one with the contrast as for the regular treatment planning. Both 3D image sets were co-registered. The contrast enhanced CT set was used for creating the treatment plan and then that plan was mapped with the identical parameters onto the non-contrast CT set to simulate the dose distributions under clinical conditions. The built-in inhomogeneity correction was used for calculating the dose distributions for both CT sets. Effects for tumors in the brain, abdomen and lung were studied. **Results:** Depending on the treatment site, the complexity of the plan, the beam distributions and pathlength traveled through the contrast enhanced regions, the dose difference calculated was as high as ~3%. The deposited dose calculated based on the contrast enhanced CT set can be an over-estimate or an under-estimate, depending on the ratio of the contrast content in the tumor volume versus that in the beam pathway. **Conclusion:** While no clinically significant effect was observed in out tests for the fractionated therapy, the calculated dose difference caused by the intravenous contrast media at the simulation time is an additional systematic factor that contributes to the total delivered dose uncertainty. We expect to see more complicated effects in the IMRT treatment plans with complicated field fluences. Also for the stereotactic radiosurgery treatments 3% dose difference may deem the plan to be unacceptable.

SU-FF-T-356

From Unit Density to Heterogeneity Corrected Treatment Planning for Lung Cancer: A Monte Carlo-Based Dosimetric Analysis of the Effects On Prescription Dose

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Purpose: Conventional radiotherapy of lung cancer assumed that the patient was composed entirely of unit-density tissues. Since biological response is correlated with actual physical dose, implementation of heterogeneity corrections should be made with caution in order to achieve the same or better clinical results. In this study we study the changes needed in prescription dose when making heterogeneity corrections. **Method and Materials:** Treatment plans for 21 previously treated lung patients were regenerated using Monte Carlo with and without heterogeneity corrections. Dose volume histograms, isodose distributions and 50% target coverage (D50) were examined. Additionally, the amount of target surface abutting lung tissue and total dose delivered via oblique angles were analyzed to correlate with the actual physical dose received by the patients. **Results:** The percent difference between D50 values obtained for unit-density plans and full heterogeneity corrections ranged from 0.2-8.2% and –0.1-5.0% with average values of 3.7% and 1.1% for right and left lung lesions, respectively. The difference in D50 with >50% and <50% of the target surface bounded by lung tissue ranged from 0.6-5.1% and –0.1-8.2% with average values of 3.3% and 2.0%, respectively. Differences when >35% or <35% of the dose is delivered through oblique angles ranged from –0.1-8.2% and –0.1-6.6% with average values of 3% and 1.6%, respectively. In all only 3 of 21 cases showed >5% difference in D50. **Conclusion:** Our results indicate that it may not be necessary to adjust prescribed dose for lung lesions when applying heterogeneity corrections since the actual physical doses delivered to the target were as expected. Poor target coverage might be responsible for some of the local failures. Higher prescription doses may be used for lung treatment to improve local control if normal tissue sparing can be improved with advanced dose calculation and beam delivery techniques.

SU-FF-T-357

Modeling Thick-Target Bremsstrahlung Production by Compound-Poisson-Process Electron Multiple Scatter

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Purpose: To develop an accurate analytic algorithm to model bremsstrahlung production in a linac target and to calculate the angular distribution of the primary photon energy spectrum. This provides an alternative to Monte Carlo calculation of the primary photon spectrum.

Method and Materials: The Compound-Poisson-Process (CPP) method is used to calculate the directional distribution of electrons in the target at each depth, explicitly including multiple scatters at large angles. This CPP method is modified to include the electron loss of energy at depth in the thick target. The Schiff integral formula is used to compute the bremsstrahlung spectrum produced at each angle and depth, and the contributions are integrated over depth to yield the photon energy fluence spectrum as a function of polar angle. This formula makes no small-angle approximations, so it should be accurate at all angles. **Results:** The primary (and attenuated first-scatter) photon energy fluence distribution was computed for a 15 MeV electron beam incident on a thick lead target and compared to a measurement in the same geometry. **Conclusion:** It is hoped that an accurate analytic calculation of the bremsstrahlung energy fluence distribution emerging from a linear accelerator treatment head will provide a quick and useful alternative to Monte Carlo calculations of this same distribution.

SU-FF-T-358

MRI-Based Treatment Planning for Radiotheraphy of Brain Lesions

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Purpose: The purpose of this work is to investigate the practicality of a treatment planning method based only on magnetic resonance imaging (MRI) for radiotherapy of brain patients. **Method and Materials:** MRI is the preferred imaging modality for target delineation because of its superior soft tissue contrast. The main drawback of this modality for treatment planning of intracranial lesions is the lack of electron density information in the MR images. To overcome this limitation, we assigned electron density values to anatomical structures based on contours. We used clinical data acquired on a 1.5T Intera MRI scanner to compare the MR and CT+MR-based treatment plans. To asses the effectiveness of the contouring procedures we used 1.5T and 3.0T MR images. The outlines of the skin, bone and brain were obtained by using a combination of autocontouring and profile tools available on Pinnacle and AcQSim MR. The treatment plans corresponding to CT+MR and MR-based methods were generated on Pinnacle RTP software, by using the same beam angles, dose constraints and optimization parameters. **Results:** The CT+MR and MR-based treatment plans were compared in terms of isodose distribution and dose volume histograms. The results are in good agreement. The average electron density value assigned to bone can be determined as a function of the threshold level set for the autocontouring procedure. MR image distortion artifacts were not an important factor, due to a small field of view and the use of a head coil. We found that the 3T T2-weighted images are the best candidate for contouring structures due to their superior contrast. **Conclusion:** Treatment plans based entirely on MR images produced similar results to CT+MR-based plans. Using MRI simulation, image fusion errors such as variations in patient setup and uncertainties in identifying similar structures between CT and MR are eliminated.

SU-FF-T-359

Optimization of Treatment Plans for Extracranial Stereotactic Lung Radiotherapy – RTOG 0236

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Purpose: To evaluate a computer-assisted methodology that optimizes 3-D conformal radiotherapy treatment plan with minimal human intervention. The intent was to maximize the planning target volume (PTV) dose while minimizing the dose to normal tissues for stereotactic radiotherapy of lung tumors. **Method and Materials:** The Elekta Stereotactic Body Frame (SBF) immobilized the patients and provided stereotactic coordinates for localization of the PTV. Registration plates uniquely and reproducibly positioned the SBF on the CT-simulator and linac couches. Consequently, we could obtain a mathematical transform between linac couch coordinates and stereotactic coordinate system defined by Elekta Prec*i*sePLAN (EPP) planning system. We measured linac couch and gantry angles that avoided collision of the gantry with the registered SBF and couch for representative treatment positions. This data allowed creation of templates for EPP, each consisting of over 40 non-coplanar beams arranged approximately 30 degrees apart. In addition to PTV and organs at risk, two contoured anatomical structures aided in optimization and evaluation of the treatment plans: a rind around the PTV and a rind of tissue adjacent to the patient's skin. Unattended optimization took about 45 minutes after setting the DVH specifications in EPP's aperture-based optimization tool for appropriate contoured anatomy. We selected 7-10 beams with greatest number of monitor units (typically, >350 per fraction) for the final plan. Evaluation of the treatment plans employed the following statistical indicators: %PTV encompassed by the prescription dose, ratio of the 50% prescription volume to PTV, and maximum dose > 2 cm from the PTV. **Results:** Comparison of statistical indicators for several clinical cases showed that the unattended optimization was favorable to that by a human operator in less time and effort. **Conclusion:** This methodology can increase the efficiency of 3-D conformal treatment planning. **Conflict of Interest:** Partly funded by Elekta, Inc., Norcross, GA.

SU-FF-T-360

Software Tools for 4-D and Adaptive Treatment Planning Data Visualization and Manipulation (CERR Version 3)

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Purpose: Open-source tools are needed to facilitate the use of multiple imaging datasets for adaptive and 4-D treatment planning. Commercial systems do not yet provide effective solutions for reviewing, manipulating, and comparing multiple scan datasets taken at different times of with different imaging modalities. Our research treatment planning system, CERR ("computational environment for radiotherapy research," pronounced 'sir'), provides a convenient and powerful basis for constructing adaptive and 4-D treatment planning tools. **Method and Materials:** The flexible Matlab-based system CERR was modified and extended. A fast algorithm for image registration was developed and integrated with CERR. **Results:** We have added support in CERR for: (1) multiple patient image sets, which can be combinations of CT, MRI, or PET scans, and corresponding anatomical structure datasets, (2) rapid image registration (by hand as well as by using an automated method), (3) visualization tools appropriate to review anatomic structure changes with different scan sets, and (4) linked-storage of multiple scan sets, eliminating memory limitations. In addition, many smaller features have been added to CERR, such as interactive profile plots of dose and/or image values. This version of CERR also provides support for IMRT treatment planning simulations. Local data storage in a sub-directory or network scan data storage we integrated. Flexible reporting tools allow for structures defined on one dataset to be combined with dose distributions computed for another scan, and resulting dose-volume-histograms can be easily derived. The latest release can be downloaded from radium.wustl.edu/cerr. **Conclusion:** CERR version 3 provides foundational tools for research in adaptive and 4-D treatment planning. This framework provides a powerful basis for experimenting with deformable imaging methods, as well as other adaptive radiotherapy challenges, such as re-optimization research.

SU-FF-T-361

Dose Distribution in Extracranial Radiosurgery: A Comparison with Step and Shoot IMRT Based On Dose Indexes

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Purpose: To compare Extracranial Radiosurgery dose distributions to step and shoot Intensity Modulated Radiation Therapy (IMRT) aimed to the same dose prescriptions and constraints. **Method and Materials:** 12 patients treated by means of the Cyberknife system for extracranial tumors (7 lung, 2 pancreas, 2 liver and 1 prostate) were selected. Volume of the PTV ranged from 19.0 cc to 584.4 cc. The prescribed doses were 16-27 Gy to the 80% isodose surface in 1-3 fractions. IMRT treatment plans were calculated to obtain the same coverage of the PTV with same constraints to organs at risk. A 5-coplanar fields, step-and-shoot technique was employed with a 6MV accelerator. IMRT plans were generated by means of the Pinnacle treatment planning system. We compared homogeneity and conformity indexes and ratios between isodose volumes. Furthermore, a recently proposed index for comparison of radiosurgery plans was calculated. The new index balances conformity and steepness of the gradient outside the PTV. **Results:** Homogeneity index ranged from 1.35 to 2.00 (mean 1.54) for the Cyberknife and from 1.10 to 1.64 (mean 1.26) for IMRT. Conformity index ranged from 0.76 to 1.28 for the Cyberknife

and from 0.79 to 2.55 for IMRT; the mean deviation of the conformity index from 1 was 0.14 and 0.74, respectively. The ratio between 20% and 80% isodose volumes ranged from 4.0 to 28.0 (mean 12.9) for the Cyberknife and from 9.7 to 38.3 (mean 21.7) for IMRT. Results obtained with the new index confirmed the behavior observed with the conformity index. **Conclusion:** Conformity resulted in general better for the Cyberknife while homogeneity resulted in general better for IMRT. The ratio between volumes of mid-low isodose surfaces (10% - 50%) to the volume of the reference isodose surface (80%) resulted higher for IMRT than for the Cyberknife.

SU-FF-T-362

Dynamic MLC for a Simpler 4-Field Single Isocenter Breast Technique: Development, Commissioning and Verification

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Purpose: Using dynamic multi-leaf collimation both for lung shielding and wedging of tangential breast fields, we created a simple, single isocenter breast technique, without blocks or physical wedges. This technique serves as a valuable intermediate step between traditional and full-fledged IMRT of the breast and superclavicular regions. **Method and Materials:** We use a treatment planning system to determine wedge angle and shielding for the tangential fields. Dynamic MLC files are generated by combining the shielding and wedge angle using the Varian EDW GSTT tables. Concomitant boost fields are optional. We used film and EPI to commission and verify the dynamic MLC wedge. **Results:** Dynamic MLC wedge techniques to differ from traditional EDW treatments. Transmission through the MLC leaves, especially in the interleaf region and changes in head scatter and back scatter to the monitor unit chambers due to the increases source to wedge distance. These factors cause the delivered wedge angle to be slightly shallower than that delivered by an EDW for a given planned angle. We used film to commission the dynamic MLC wedge delivery. For routine wedge angle verification, we found EPID to reproducible, accurate and most convenient. By delivering 300 MU at 300 MU/min we could easily distinguish MLC wedges in 5° increments. **Conclusion:** Incorporating dynamic MLC files as both shielding and wedging for breast fields is an easily implemented step towards IMRT. It simplifies the 4-field single isocenter breast technique by eliminating the need for block fabrication and expediting beam delivery.

SU-FF-T-363

Dynamic Tangents and Topotherapy: New Delivery Capabilities for Helical Tomotherapy

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Purpose: Analyze new capabilities for planning and delivery of helical tomotherapy using very loose pitch and also fix angle gantry deliveries while the couch is moving in and out of the gantry. Compare these deliveries respect to typical helical tomotherapy deliveries created using small pitch. **Method and Materials:** In a typical tomotherapy plan, the delivery is achieved using a binary (MLC) in a rotating gantry while the couch is moving with pitch typically smaller than 1. In this manuscript two new planning and delivery capabilities were developed. The first one, topotherapy has the gantry fixed at few angles (no rotation) while the couch moves and the MLC modulate the beam. After the delivery of a direction is finished the gantry move to a new fix position and the same process is repeated. In the second method, dynamic tangents, the gantry is rotating slowly in an small arc and the couch is moving while the leaves are modulating. The techniques were used in simulated breast treatments. **Results:** Topotherapy and dynamic tangent are good alternatives for plans where the more important beam directions are easily determined. In topotherapy, pitch regulates the degree of modulation inferior-superior. The dynamic tangents technique can achieve the same level of target coverage as topotherapy. However, dynamic tangents can further reduce the dose to surrounding normal tissues. Both techniques can achieve very uniform dose distributions without increasing the dose to normal tissues. **Conclusion:** Helical tomotherapy allows delivering very sophisticated plans. However, for certain anatomical sites where the number of beam directions will not impact the plan quality (such as breast, palliative, AP-PA, etc) topotherapy and dynamic tangents can be implemented more efficiently. For these simple cases, good dose uniformity and coverage can also be achieved without compromising normal tissue irradiation. **Conflict of Interest:** TomoTherapy-Inc.

SU-FF-T-364

Photo-Electric Effect with a Vengeance: Dosimetric and Microdosimetric Characterization of Contrast-Enhanced Radiation Therapy Using Kilovolt X-Rays

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Purpose: To quantify the dose enhancement (DE) in tumors labeled with contrast medium and irradiated by kilovolt x-rays in Contrast-Enhanced Radiation Therapy (kV-CERT). To study the microdosimetric changes in radiation quality in the same. **Method and Materials:** DE in the presence of contrast media (CM, I or Gd-based) in slab geometries was studied with a Monte Carlo model (validated against measurements) as a function of photon energy and concentration. Two simulated clinical test cases were studied for a spherical tumor labeled with CM embedded in the brain or lung region. In both cases a CT-like arc was used as source geometry. To investigate microdosimetric radiation quality changes in the CM regions dose mean lineal energy, y_D, was calculated. **Results:** In slab geometries irradiated with mono-directional x-ray beams maximum DE of about 6-8 for a I-based solution (50 mg/ml) or a Gd-based solution (79 mg/ml) were found to occur for 60 keV photons. Dose uniformity in the slab was found to depend strongly on the contrast medium concentration, the depth in the slab and the photon energy. For the brain and lung test cases dose enhancements of 4-6 were found when realistic x-ray spectra were used in an arc irradiation. A variable dose rate at different angles improved the dose uniformity in the target. For the lung test case kV-CERT was compared to a conventional 6 MV AP-PA plan. In addition to the large dose enhancement in the tumor, a dose decrease in the surrounding tissue by about 50% was noted. The changes in dose mean lineal energy in labeled tumors were limited to about 10%. **Conclusion:** kV-CERT is a technique that has the potential to enhance the dose to tumors significantly while reducing the dose to the surrounding healthy tissues. **Conflict of Interest:** Work sponsored by Siemens Medical Solutions

SU-FF-T-365

Measurement of Radiation Induced Lung Damage in the Rat by CT Image Analysis

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Purpose: To design a method to quantify morphological changes in irradiated lung tissue, assessed by CT. **Method and Materials:** CT images were made at different time points after administration of varying doses to different regions of the rat lung. The experiment included irradiation of 100%, 50% (6 different regions) and 25% (2 regions) of the total lung volume. The applied doses were: 9,10,11 and 12 Gy for the 100% lung volume, 16,18,20 and 22 Gy for the 50% volumes and 27,30,33 and 36 Gy for the 25% volumes. A computerized contouring method was developed to automatically delineate the lungs in the CT images. For each irradiated region the average CT-value (ACV) of its pixels and its standard deviation (SD) were determined. The changes in ACV and its SD with respect to the same region in controls were combined in a vector M. The length and orientation of M was used to characterize the changes in the CT image pattern, i.e. the morphology of the lung tissue. The total lung volume of all animals and M were measured at 8, 26 and 38 weeks for all irradiated regions, averaged over all dose values. After normalization, M was also measured as a function of dose. **Results:** About 13.000 contours in lung volume studies of 374 rats were automatically drawn. With respect to the controls, a decrease in total lung volume in time was observed. Significant changes in radiation responses M were found in all irradiated regions. The largest radiation response was found for lateral lung volumes. **Conclusion:** The auto-contouring method is very robust and can easily be applied to process large amounts of CT-slices of irradiated rat lung. The

method showed significant changes in average lung CT pixel values and their variation for sub volumes of irradiated lung tissue.

SU-FF-T-366

Radiation Dose Response Curve of Human Cerebral Cortex Measured with [F-18]-FDG and [O-15]-H2O PET Imaging

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Purpose: To study radiotherapy (RT)-induced dose-dependent functional changes in the human cerebral cortex region using serial ^{18}F-FDG and ^{15}O-H_2O PET imaging before and after RT. **Method and Materials:** Eleven human subjects were enrolled in an IRB-approved prospective study to quantitatively measure changes in post-RT brain function. ^{18}F-FDG and ^{15}O-H_2O PET images were taken pre-RT, and again at 3 weeks and 6 months post-RT, to quantitatively assess for RT-induced changes in relative metabolism and relative regional blood flow (RBF). The 3 week and 6 month follow-up evaluations were available for 7 and 6 patients, respectively. Follow-up images were registered to their corresponding pre-RT baseline images, as well as to the treatment planning CT/MRI scans, for quantitative analysis. Relative changes in regional ^{18}F-FDG and ^{15}O-H_2O PET activities were related to regional RT dose. Regions of the cerebral cortex receiving <5Gy served as "controls" for imaging normalization. Irradiated regions were binned, based on 5Gy intervals, up to 62Gy. Individual and population dose response curves were then generated in PLUNC (PlanUNC). **Results:** At both post-RT time intervals, stable reductions in relative FDG uptake (average 2-6%, range -8 to 13%, generally <8%) were seen in the cerebral cortex, particularly in the regions receiving >40-50Gy. Initially, relative RBF increases (generally <10%) were observed on 15O-H2O PET imaging (3 week follow-up), but were much less significant at the 6-month follow-up. **Conclusion:** The response of cerebral cortex tissue to RT can be detected, in a dose-dependent manner, using ^{18}F-FDG PET. The magnitude of the changes, however, was typically small (<8%). Initially there were increases in relative RBF, but no discernable changes were seen at 6 months followup in ^{15}O-H_2O PET. Further studies are needed for more conclusive results. Results from neuropsychological testing will be used to assess the potential clinical impact of the changes measured by PET.

SU-FF-T-367

What Does the Dosimetric Errors Encountered in Prostate Brachytherapy Tell Us About the Alpha/beta Ratio

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Purpose: Use the linear quadratic model to evaluate the α/β ratio for prostate cancer taking into account the dosimetric errors resulting from seed displacements in prostate permanent implant brachytherapy with ^{125}I and ^{103}Pd. The study tests the sensitivity of the α/β ratio for different values of the prescribed external radiation dose, different published values of the Relative Biological effectiveness (RBE) for both ^{125}I and ^{103}Pd and different prescribed implanted dose. **Method and Material:** The biological effective dose (BED) for prostate implant brachytherapy is equated to the external radiation therapy dose to derive an equation for α/β ratio. α/β ratio is then determined for different values of the implanted ^{125}I or ^{103}Pd dose and for different published values of the RBEs. The analysis took into account dosimetric errors resulting from inaccurate placement of seeds or seed movements after placement. The dosimetric uncertainties were previously determined from Monte Carlo simulation model which accounted for the seed positioning errors. **Results:** The results showed that the α/β ratio for prostate cancer varies between 1.0 and 4.5 for an RBE of 1.0 for an external prescribed dose of 78.0 Gy. When published values of RBEs are incorporated into the analysis, the α/β ratio varies between 0.37 and 4.4. For RBE values ranging from 1.0 to 2.0, α/β ratio decreases from 1.55 to 0.55 for an implanted dose of 145 Gy and an external beam dose of 78 Gy. The α/β ratio changed by 30% when the external beam radiation dose was increased from 72 Gy to 80 Gy. **Conclusions:** The α/β ratio for prostate cancer is uncertain and could be as low as 0.37 and as high as 7 depending on which factors have been incorporated into the analysis. Taking an average reduction in implanted dose of 10-20%, realistic values of α/β ratio for prostate tumor lies between 0.7 and 3.0

SU-FF-T-368

A Biophysical Model for Adaptive Radiotherapy Based On Tumor Volume Regression During Radiation Treatment

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Purpose: Tumor volume regression is frequently seen during the course of radiotherapy (RT). Adaptive RT (ART) considered so far is mainly geometric, (adapting radiation fields to the changing geometry of the tumor). Biological ART, (adapting radiation dose for individual patients), is the ultimate goal. The purpose of this work is to develop a biophysical model that can be used to biologically adapt RT based on tumor volume regression during the RT treatment course. **Method and Materials:** The survival fraction after n fractions can be calculated as $(SF_2 2^{1.4/T_{pot}})^n$, where SF_2 is the surviving fraction at 2 Gy and T_{pot} is the potential doubling time. Based on this expression and other considerations, a formula to relate SF_2 with the residual tumor volume during RT was developed. Two previously reported clinical data sets on tumor volume measurements during RT for cervical were used to validate the model.
Results: The SF_2 can be related to the tumor volume regression during treatment as $(SF_2)_{eff} \equiv SF_2 2^{1.4/T_{pot}} \approx \rho_2 e^{\frac{1}{n}(1-\frac{1}{v_n})}$, where v_n is the relative tumor volume after n fractions, ρ_2 is the relative clonogenic cell density after a 2Gy fraction. The calculation of TCP versus volume regression is consistent with clinical results from two published cervical cancer studies. The calculation of TCP as a function of SF_2 indicates that certain group of patients could benefit from dose escalation. Based on the model developed, we have calculated the extra dose needed to compensate for a poor response to radiation according to tumor volume regression. **Conclusion:** A biophysical model that predicts the treatment effectiveness based on the measured tumor volume during the course of RT is developed. The model prediction is consistent with that observed in the clinic for cervical cancer. The model can predict whether the patient would benefit from dose escalation. More clinical data are required to validate our model.

SU-FF-T-369

An Estimation of Radiobiological Parameters From Clinical Outcomes for Radiation Treatment Planning of Brain Tumor

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Purpose: Appropriate organ-specific radiobiological parameters are crucial for biologically-based treatment planning. The purpose of this work is to derive a plausible set of such radiobiological parameters for malignant gliomas (MG) based on clinical outcomes. **Method and Materials:** Several radiobiological models, including the linear quadratic formalism with consideration of repopulation and repair, tumor control probability and equivalent uniform dose, were used to analyze a series of published clinical data for MG involving different regimens of radiation therapy. The least chi-square χ^2 fitting technique was employed to estimate the LQ parameters. **Results:** A plausible set of LQ parameters: $\alpha = 0.08 \pm 0.02$ Gy^{-1}, $\alpha/\beta = 11.4 \pm 8.6$ Gy, the tumor cell doubling time $T_d = 50 \pm 30$ days, with the repair halftime of 0.5 h was obtained for gliomas. The presently estimated biological parameters reasonably predict the effectiveness of the most of recently reported clinical results employing either single or combined RT modalities. In addiation, the radiosensitivity for grade III and VI astrocytoma was found to be: $\alpha = 0.18 \pm 0.03$ Gy^{-1}, $\alpha/\beta = 6.0 \pm 4.1$ Gy and $\alpha = 0.09 \pm 0.04$ Gy^{-1}, $\alpha/\beta = 9.0 \pm 9.8$ Gy respectively. For Grade III, our result agreed with the published *in vitro* data, while for Grade 4, the α and α/β values estimated presently based on clinical data are smaller than those from *in vitro* measurements, indicating lower radiosensitivity occurred *in vivo* as compared to *in vitro*. The derived α and α/β values demonstrated that GBM is quite radioresistant as known from clinical practice. **Conclusion:** The radiobiological parameters derived presently for MG can reasonably predict the most of the recently reported clinical results

employing either single or combined RT modalities. These parameters can be potentially useful in evaluating, optimizing, and designing biological/functional image guided IMRT strategies.

SU-FF-T-370

Biological Analysis for Hypofractionated Lung Cancer Radiotherapy

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Purpose: Hypofractionationated SRT for medically inoperable early stage primary lung cancers has gained great interest in radiotherapy society. This work analyzes the tumor control probabilities (TCP) and lung complication probability (LCP) for fractionated radiotherapy and SRT of lung cancer. **Method and Materials:** Calculations were performed for hypofractionated scheme using 10 Gy/fraction for 4 fractions and for standard fractionation using 2 Gy/fraction in 30 fractions. A linear-quadratic (LQ) model was used in the TCP analysis. A quantal model was used for the LCP calculation. The dose inhomogeneity was assumed with a Gaussian distribution with a deviation of σ_{dose}. The variation of radio-sensitivity for a patient population was added assuming Gaussian distributions for LQ parameters α and β with σ_{α} and σ_{β}, respectively. The TCP and LCP were compared for the two fractionation schemes. **Results:** As σ_{α}, σ_{β} and σ_{dose} increase, more doses are needed to keep the same 90% TCP. Because the equivalent dose EQD2 for hypofractionated SRT is much higher than the standard prescription dose of 60Gy, its corresponding TCP is always higher compared to standard radiotherapy, and in most cases, it is always greater than 90%. However, because of the higher EQD2, the LCP for hypofractionated lung SRT is also much higher. For the 4 cases studied here, the average LCP for SRT is increased by 100% compared to standard radiotherapy. Further studies are conducted using DVHs from standard radiotherapy with a 1cm MLC and DVHs from SRT with a 0.4cm mMLC to investigate the improvement in LCP and TCP. **Conclusion:** Hypofractionated SRT provides better tumor control for lung cancer. However, it may lead to severe lung complications unless advanced target localization, treatment planning and beam delivery techniques are used to reduce the lung volume receiving significant radiation dose.

SU-FF-T-371

Equivalent Stochastic Dose (ESD): Quantifying the Impact of Dose Uncertainties On Radiotherapy Treatment Plans

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Purpose: To study the impact of dose uncertainties on radiotherapy treatment plans through the use of survival fraction. **Method and Materials:** We considered the case, where the total dose to a volume element has an associated uncertainty. To distinguish between spatial and probabilistic dose heterogeneities, we define *equivalent stochastic dose* (ESD) as the dose that results in a mean survival fraction for a randomly deposited dose to a volume. For a probability density function, f(D), that represents the dose to a voxel, SF(ESD) can be calculated using the convolution technique. In the case where the probability density function follows a Gaussian distribution, an analytic expression has been derived for SF(ESD). The expression has been verified using the Monte Carlo method for various radiosensitivities and α/β ratios. **Results:** The results show that survival fraction increases with an increased dose uncertainty and was found to be dependent on the radiobiological parameters. Using the analytic expression for SF(ESD), dose uncertainty can be evaluated for any voxel or group of voxels in the dose matrix, including those in an OAR and/or PTV. For spatially Gaussian dose distributions a statistical uncertainty of 2% was found to result in an average *equivalent uniform stochastic dose* (EUSD) of 98% with respect to the modelled mean dose. As the dose uncertainty increased beyond 5% the ratio of EUSD to prescribed dose dropped rapidly. **Conclusion:** In this work, statistical and physical dose uncertainties have been combined in a formalism that concurrently quantifies the impact of each on survival fraction. The effect of dose uncertainty can easily be evaluated for any voxel in the dose matrix including the PTV and OAR volumes. This can be useful in the assessment of planned treatments when dose uncertainty estimates are known.

SU-FF-T-372

Evaluation of the Limits of Accuracy of the High Heterogeneity TCP Model

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Purpose: To determine the limits of accuracy of a TCP model that assumes high heterogeneity, such as the Roberts and Hendry (*IJROBP* **41** 689-699 1998) model. **Method and Materials:** A TCP model that incorporates heterogeneity in radiosensitivity, clonogen number and growth rate is reduced to a two parameter model by grouping variables using a method previously introduced by Carlone et al (Carlone et al *Med Phys* **30** 2832-2848 2003). The model is then approximated in the high heterogeneity limit by approximating the TCP function as a Heaviside step function with a step at 0.577. The high heterogeneity approximation, when plotted in the reduced parameter space has iso-TCP lines that are linear, and cross at a common point. This suggests a further variable reduction such that TCP depends on a single variable, δ: TCP = ½ *erfc*(δ/sqrt(2)). A similar variable substitution can be inserted into the exact TCP model; the result is a function of two variables, however the TCP function depends much more strongly on the variable δ than on the second variable. The limits of accuracy of the approximation are determined by calculating the difference between the two solutions. **Results:** When only heterogeneity in α is considered, the high heterogeneity TCP approximation is accurate (< 5%) when $\sigma_{\alpha}D$ is larger than 1.6. When $\sigma_{\alpha}D$ is large as compared to 0.577, the TCP function can be accurately evaluated using only parameter ratios (Roberts and Hendry closed formula), however it does depend on the value of σ_{α} when $\sigma_{\alpha}D \approx 0.577$. When σ_{α} is small, maximum errors on the order of 30% to 50% can occur. **Conclusion:** When the quantity $\sigma_{\alpha}D$ is significantly larger than 1, the heterogeneous TCP function can be accurately modeled using only parameter ratios, and the high heterogeneity approximation.

SU-FF-T-373

Fitting the Zaider-Minerbo TCP Model to Cell Megacolony Culture Dose Response in Vitro Data

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Purpose: To investigate the effects of radiation damage, tumor repopulation and cellular sublethal damage repair. **Method and Materials:** An expression of the Zaider-Minerbo model obtained by Stavreva *et al*. is used to fit published dose-response *in vitro* data from two cellular megacolony cultures. **Results:** The data analysis shows the importance of the linear-quadratic mechanism of cell damage for the description of *in vitro* cell dynamics. In a previous work, where *in vivo* data were analyzed, the employment of the single hit model and cell repopulation produced the best fit, while ignoring the quadratic term in the current analysis leads to poor fits. Also, the best-fit value of the probability of sublethal damage repair, τ, for both cell cultures tends to infinity, indicating that full recovery of the cells occurs between any two consecutive fractions. **Conclusion:** We conclude that the Zaider-Minerbo model assuming full recovery of the cells between fractions accompanied by cell repopulation best fits the data from both cellular cultures investigated in the current work. However, a model assuming no repopulation returned a fit statistically indistinguishable from the fit produced by the Zaider-Minerbo model, though at the expense of unusual best fit values of the cell radiosensitivity characteristics and a large value of τ. Therefore, we recommend the design of experiments using different fractionation regimes producing diverse data to help better analyze the TCP models and rank the models in accordance with statistical criteria.

SU-FF-T-374

Halftime for Repair of Sublethal Damage in Normal Bladder and Rectum: An Analysis of Clinical Data From Cervix Brachytherapy

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Purpose: The purpose of this work is to resolve an apparent contradiction between previously reported values of repair time (t_{rep}) for the normal bladder and rectum, as normal structures of cervical cancer. We reconcile previous analyses of clinical data and introduce new evidence to support a

short repair time for these normal structures. The implications of a short repair halftime for critical structures on LDR versus HDR brachytherapy treatment planning are discussed. **Method and Materials:** Urinary and rectal complications from gynecological radiation therapy are analyzed as a whole to derive a unique repair time for the normal bladder and rectum. The concept of biologically effective dose (BED) based on the linear-quadratic (LQ) model is used to compare treatment modalities**.** We analyze three published clinical studies that compare intracavitary brachytherapy applications of two different dose-rates. We define a sparing factor f for bladder and rectum and estimate a reasonable range for it. We calculate t_{rep} as a function of the α/β ratio by equating the BED of intracavitary treatments with two different dose-rates that yield equivalent levels of complications,. **Results:** We find that if a sparing factor for the critical structures is considered, a short repair time for the normal structures (bladder and rectum) is consistent with the three clinical data sets studied. The present analysis does not support the long repair halftime component in the order of 4 or 5 hours found for other normal tissues. We find a repair time for normal bladder and rectum is in the range of 0.2-0.4h (12-24 minutes), if an α/β ratio of 3Gy is assumed. **Conclusion:** If a sparing factor for the critical structures is considered, the three clinical data sets studied are consistent with a short repair time for the normal structures (bladder and rectum).

SU-FF-T-375

Machine Learning Methods for Radiobiological Outcomes Modeling

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Purpose: Radiobiological outcomes models are important predictors of irradiation induced effects in terms of achieving tumor control or causing damage to surrounding normal tissues. They are also used to rank the quality of treatment plans. Outcomes models may depend on many variables such as dose-volume metrics and clinical factors. *In particular, the best outcome model itself may vary depending on patient or treatment characteristics.* General non-linear models, such as neural-networks, potentially allow us to capture this natural variation in models. **Method and Materials:** We studied feed-forward (FFNN) and general regression neural networks (GRNN). As representative data, we used a cohort 166 non-small cell lung cancer patients who received radiotherapy treatment, with endpoints of pneumonitis and esophagitis. Dosimetric variables were extracted using CERR. **Results:** We used resampling (bootstrap) methods to select optimal parameters for the networks, which include the number of neurons in FFNN's and the 'width' (σ) in GRNN's. In modeling pneumonitis, the optimal FFNN had 3 layers and 5 neurons in the hidden layer, with spearman rank correlation 0.49±0.27 in training and 0.11±0.07 in testing. The GRNN with σ=1.25, achieved a training spearman of 0.25±0.08 and testing spearman of 0.20±0.3. In modeling esophagitis, the FFNN had 5 neurons, with a spearman of 0.59±0.09 in training and 0.3±0.21 in testing. GRNN with σ=1.25, achieved a training spearman of 0.38±0.06 and a testing spearman of 0.39±0.12. **Conclusion:** We evaluated two machine learning algorithms to model outcome in cases of pneumonitis and esophagitis. Our preliminary results indicate that the GRNN was more straightforward to implement and, more importantly, had better generalizability than that of FFNN. Our experience to date indicates that neural networks may perform as well or better than multi-term logistic regression methods.

SU-FF-T-376

Multi-Variable Modeling of Radiotherapy Outcomes: Determining Optimal Model Size

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Purpose: The probability of a specified radiotherapy outcome (e.g., a normal tissue complication or tumor eradication) is typically a complex, non-linear, unknown function of dose distribution characteristics and clinical factors (such as chemotherapy, age, gender, diabetes, etc.). However, current outcome models are usually over-simplified, and standard model fitting methods give little guidance as to how to best add choose from many complicated, alternative models. We discuss methods for building multivariable response models within the framework of logistic regression. We study in detail the issue of how to select model complexity to reach the goal of maximizing predictive power. **Method and Materials:** Analyses of esophagitis and xerostomia datasets are used as examples. We describe techniques for approximating the unknown dose-volume-response function as a linear combination of multiple candidate dosimetric variables and clinical factors. In order to guard against under- and over-fitting, we compare several methods for selecting optimal model size, including: fitting against bootstrap training and testing datasets, Akaike information criteria, and leave-one-out cross validation. **Results:** Leave-one-out cross validation produced the most unambiguous guidance for optimal model size. Optimal esophagitis model size was five variables (concurrent chemotherapy, A55, A30, A45, A85). Although the xerostomia model could be improved using clinical factors, the improvement over using the single dose-volume model term was small, and therefore judged not worth the added complexity. **Conclusions**. Treatment response models, including dose-volume effects, can be made more predictive by mixing clinical and multiple dose-volume factors into a single model. Over-simplified treatment response models are only justified in those cases where more complicated models cannot be supported by the data. Leave-one-out cross correlation model testing combined with Spearman's correlation coefficient often provided the least ambiguous method to study the tradeoff between prediction improvements and model size and to choose optimal model size.

SU-FF-T-377

Theory of Parameter Correlation in a Population Tumor Control Model Assuming High Heterogeneity in the Radiosensitivity

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Purpose: In this work we present a theoretical investigation of the parameter correlation in a population tumor control model assuming high population heterogeneity in the radiosensitivity. **Method and Materials:** A number of authors have shown that ambiguity exists when radiobiological parameters are obtained by fitting population dose response data with a heterogeneous (population) tumor control model. The difficulty is that many different sets of parameter values can be used to construct TCP curves that are identical. These sets of parameters may be described as linear combinations of parameters. We use the Roberts and Hendry (1998 *IJROBP* **41** 689-699) closed formula to investigate this ambiguity. **Results:** The Roberts and Hendry closed formula can be reduced to depend on two generalized parameters. For our analysis we introduce the following notation: $TCP = \Phi(\delta)$, $\delta = (\gamma - \kappa)/\sigma$, where $\kappa = (\alpha + \beta d - \lambda/d)D - \ln(k)$, $\sigma = \sigma_\alpha D$, and $\gamma = 0.577$ (Euler gamma constant). When the model is plotted in the κ–σ space, the iso-TCP lines are linear, and intersect at the point $\kappa = \gamma$, $\sigma = 0$. Parameter correlation occurs when combinations of $\alpha' = (\alpha + \beta d - \lambda/d)$, σ_α and $\ln(k)$ produce the same value of TCP for any value of the dose, D. This correlation can be proven by two methods: analytic or geometric. The specific form of the parameter correlation is: $\alpha' D_{50} - \ln(k) = \gamma$, ($D_{50}$ is the dose D where TCP(D)= 50%) and $\sigma_\alpha/\alpha' =$ constant. **Conclusion:** When fitting a high heterogeneity TCP population model to clinical data, parameter correlation between the quantities $(\alpha + \beta d - \lambda/d)$ and $\ln(k)$ exist. A linear relation characterized by a slope of $1/D_{50}$ represents this correlation.

SU-FF-T-378

Tumor Resensitization During Fractionated Radiotherapy: Modeling and Fitting Data From Animal Experiments

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Purpose: To further develop the modeling of tumor dynamics, we propose a mechanism of tumor resensitization based on reoxygenation, leading to the derivation of a time-dependent expression for the radiosensitivity, $\alpha(t)$, that can be incorporated into tumor control probability (TCP) models used to fit fractionated dose response data. **Method and Materials:** To model the process of reoxygenation, we first assume that a tumor's radiosensitivity is dictated by the oxygenation level of an inner core of tumor cells, which is initially hypoxic, and thus radioresistant. Using an equation to describe the diffusion of oxygen to this inner core from outer tumor layers, and by presuming a relationship between α and the oxygen concentration, an expression for $\alpha(t)$ can be derived. This expression is then incorporated within a TCP model that already includes tumor cell repopulation and repair. We fit a published set of experimental animal TCP

curves corresponding to several different fractionation regimes using both the modified (with resensitization) and unmodified (without resensitization) versions of the TCP model. To investigate the importance of the β mechanism, we also fit a version of the model *with* resensitization in which the linear-quadratic (LQ) parameter β was set to zero. **Results:** The modified model *with* resensitization, and with a non-zero β component, produced statistically superior fits. Specifically, only this model was able to describe an "inverse" dose-fractionation behavior present in the data, which indicated that less dose was required to achieve a given tumor control with five fractions than with three. **Conclusion:** Resensitization and the β mechanism may be important in the description of the dose-response for a small number of fractions. Since it may in the future be possible to alter radiotherapy schemes after monitoring the tumor response in the first few treatments, consideration of such factors may prove clinically useful.

SU-FF-T-379

Biological Radial Dose Functions for Brachytherapy Sources

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Purpose: Brachytherapy is often used in combination with external-beam-radiotherapy to deliver a tumoricidal dose, while respecting critical organ tolerances. Its biological equivalence to an external beam dose fractionation has conventionally been considered via only the prescribed dose, preventing the 3D summation of brachytherapy and external beam dose distributions. We investigate a methodology that calculates a brachytherapy dose distribution biologically equivalent to an external beam dose fractionation schedule using a commercial treatment-planning system that has only conventional brachytherapy dose calculation models.

Method and Materials: Dose distributions from high-dose-rate (HDR) brachytherapy treatments, including point-source, line-source, planar, and intracavitary gynecological implants were converted to their biological equivalents for corresponding external beam dose fractionations using the linear quadratic equation and an α/β ratio of 10. The radial-dose-function (RDF) values of an Ir-192 source were modified (BRDF) to yield these biologically-equivalent dose distributions using the conventional dose calculation formalism. Use of this formalism was demonstrated by planning an IMRT treatment of cervical cancer constrained by delivered HDR dose distributions. **Results:** The BRDFs of HDR Ir-192 treatments vary as a function of external beam dose fractionations, the α/β ratio used, and implant geometry. BRDF's dependence on implant geometry is due to the nonlinearity of the linear-quadratic equation. BRDF's have non-unitary values at 1 cm from the source, depending on the equivalence of prescribed external beam and brachytherapy doses. Comparisons between the biological-equivalent dose distributions and the approximations obtained using BRDF showed excellent agreement. **Conclusion:** A method is proposed to allow calculation of biologically-equivalent brachytherapy dose distribution in commercial treatment planning systems. Preliminary studies using the BRDF demonstrated its usefulness in the IMRT treatment planning when constrained by delivered brachytherapy dose distribution. The process can also be used to review brachytherapy implant dose distributions at conventional external-beam fractionation schedules.

SU-FF-T-380

Dose Mass Histogram and Its Application for 4D Treatment Planning

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Purpose: In evaluating dose distributions of lung treated during respiration, dose volume histogram (DVH) may not be an appropriate term because of variable lung volume with respiration. The purposes of this work are to investigated the use of dose mass histogram (DMH) for lung and assess the differences between DVH and DMH for conventional and 4D treatment planning. **Method and Materials:** DMH was calculated based on a similar concept of DVH excepted mass of each voxel, which was calculated from CT number to density conversion, was used in tallying dose distributions. For conventional treatment planning, DVHs and DMHs of normal lung (excluding GTV) were calculated and compared for 51 lung cancer cases and 52 esophagus cancer cases. For 4D treatment planning, ten lung cancer cases were analyzed, each of which had 4DCT scans of full lung and optimal CT image quality. Total normal lung was delineated on CT images of all respiratory phases using auto-thresholding with a single CT number. Dose distributions were computed on all respiratory phases with DVH and DMH being calculated for the lung. **Results:** For conventional plans, difference between DMH and DVH existed for cases with highly inhomogenuous lung tissues. For a majority of cases, such differences were small and may not be clinically significant. For 4D treatment planning, lung volume changed on average by 16.3% between inspiration and expiration. As expected, variation of lung mass was much smaller, only by about 6.6% as assessed from the 4DCT. The change of lung DMH with breathing was often different from that of lung DVH, indicating that deformation of lung mass followed different patterns than that of the lung volume during breathing. **Conclusion:** DMH may be more relevant than DVH considering varying alveolar-cell density in lung and conservation of lung mass in 4D treatment planning.

SU-FF-T-381

Optimization of Radiotherapy Dose-Time-Fractionation Scheme with Consideration of Tumor Specific Biology

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Purpose: To explore the influence of the "four Rs" of radiobiology on external beam radiotherapeutic strategies for fast and slowly proliferating tumors and develop an optimization framework for tumor-biology specific dose-time-fractionation scheme. **Method and Materials:** The LQR model proposed by Brenner et al (IJROBP, 32(2), 1995) is used to describe radiation response of tumor, in which the time dependence of sublethal damage repair and redistribution and reoxygenation effects are included. The optimum radiotherapeutic strategy is defined as the treatment scheme that maximizes tumor biologically effective dose (BED) while keeping normal tissue BED constant. Simulated annealing optimization technique is used to search for the optimal radiotherapeutic strategies and the influences of different model parameters are studied. **Results:** For fast proliferating tumors the optimum overall time is similar to the kick-off time T_k and almost independent of the interval patterns. Significant increases in tumor control can be obtained using accelerated schemes for the tumors with doubling time shorter than 3 days but little gain for those with doubling time longer than 5 days. Although the incomplete repair of normal tissues has little influence on fractionation doses, when the resensitization effect included, it becomes obvious that the optimum scheme require higher fraction doses at the beginning and end of each treatment week and hyperfractionation schemes have little advantageous. For slowly proliferating tumors, hypofractionation schemes are the optimum schemes and overall time should be larger than a minimum one mainly influenced by the resensitization time. **Conclusion:** The proposed approach provided a useful tool to systematically optimize radiotherapeutic schemes for different tumors based on the differences in the "four Rs" of radiobiology between tumor and normal tissue. The results suggest that tumor site-specific optimization has great potential to improve therapeutic outcome for both fast and slowly proliferating tumors and provide useful information for designing radiotherapeutic clinical trials.

SU-FF-T-382

Planning Non-Uniform Dose Distributions for Brain Tumor

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Purpose: Inhomogeneous radiobiology exists within tumor volume of malignant gliomas as shown by biological imaging. The purpose of this project is to plan non-uniform dose distributions to account for inhomogeneous radiosensitivity using IMRT. **Method and Materials:** Sample tumor volumes were divided into several sub-regions of different radiosensitivity that may be considered to correspond to different tumor grade. A pooled clinical and in-vitro data for gliomas were analyzed to determine radiosensitivity parameters for different tumor grades. LQ model and equivalent uniform dose (EUD) were used to calculate the required radiation dose to account for different tumor grade in different sub-region. While the required dose in each sub-region is uniform, the dose distribution within the entire tumor volume is non-uniform. The Xio/CMS IMRT planning system was used to plan the required non-uniform dose distributions and also the conventional 60Gy uniform dose. The EUDs for both uniform and non-uniform distributions were compared. **Results:** Using the parameters determined from clinical data the required dose (EUD in 2Gy fractions) was found to be >55Gy for grade 1 or 2, >60Gy for grade

3 and >65Gy for grade 4. Considering low tumor grade (thus low dose) existing in periphery region, IMRT can deliver the required non-uniform distributions while keeping or improving normal-tissue sparing compared to the conventional uniform dose delivery. The dose can be escalated even higher than the required value in a high-grade region. The non-uniform dose plans yield higher tumor EUD and lower or the same normal-tissue EUD as compared to the conventional plan, indicating that the non-uniform doses are more effective. **Conclusion:** It is dosimetrically feasible to plan non-uniform dose distributions to account for inhomogeneous radiosensitivity. This prepares a framework for biological imaging guided radiotherapy of malignant gliomas, a leading cause of cancer mortality in people with young ages.

SU-FF-T-383

Prescription and Inverse Planning for Biologically Conformal Radiation Therapy

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Purpose: It is well known that the spatial biology distribution in tumors and sensitive structures is heterogeneous. Recent progress in biological imaging is making the mapping of this distribution increasingly possible. The purpose of this work is to establish a framework for quantitatively incorporating the spatial biology data into IMRT inverse planning, and to show its advantage in enhancing the TCP while reducing the NTCP.

Method and Materials: Based on a LQ model, we derive a general formula for determining the desired dose to each tumor voxel for a biology distribution characterized by the clonogen density, radiosensitivity, and proliferation rate. The desired dose distribution is used as the prescription for inverse planning. An objective function with the voxel-dependent prescription is constructed with incorporation of the nonuniform dose prescription. The functional unit density distribution in a sensitive structure is also considered phenomenologically when constructing the objective function. Two cases with different known biology distributions are used to illustrate the new formalism. For comparison, treatments with uniform dose prescriptions and simultaneous integrated boost are also planned. The TCP and NTCP are calculated for each type of plans and the superiority of the proposed technique over the conventional dose escalation schemes is demonstrated. **Results:** Our calculations reveal that it is technically feasible to produce deliberately nonuniform dose distributions with consideration of biological information. Compared with the conventional dose escalation schemes, the new technique generates biologically conformal IMRT plans that significantly improve the TCP while reducing the NTCPs. **Conclusion:** Biologically conformal radiation therapy (BCRT) incorporates patient specific biological information and provides an outstanding opportunity for us to truly individualize radiation treatment. The proposed formalism lays technical foundation for BCRT and allows us to maximally exploit the technical capacity of IMRT to more intelligently escalate the radiation dose.

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SU-FF-T-384

The Impact of Prostate IMRT On Radiation Induced Malignancies

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Introduction: The application of intensity-modulated radiation therapy (IMRT) in the treatment of prostate cancer has provided a tool to deliver high doses to the target volume while sparing surrounding critical structures. The drawback of intensity modulation, as implemented using computer-controlled multileaf collimators (MLC), is the larger number of monitor units (MU) and more beam directions used compared to conventional radiotherapy. Concerns have been raised that the widespread use of IMRT could lead to an increase in radiation-induced malignancies (RIM) due to more normal tissues being exposed to low dose radiation. **Method and Materials:** The EGS4/BEAM code was used to simulate detailed accelerator geometry to generate phase space data for the clinical beams in our department. Using patient CT data with the EGS4/MCSIM code, we calculated the dose to the patient for IMRT and conventional treatments. Based on the doses received by the risk organs away from the target we calculated the total whole-body dose equivalent and estimated the risk of RIM. **Results:** IMRT increases the leakage dose but not the scatter dose to risk organs. IMRT uses more MUs (3-8 times) than conventional treatments. For a 10MV photon beam, the estimated percent likelihood of a fatal second cancer due to 72 Gy was 0.5% for conventional treatment and it ranged from 0.6% to 1.6% for prostate IMRT depending on the energy, the accelerator/MLC design and the optimization/leaf sequence algorithms used. **Conclusion:** The increased leakage radiation due to IMRT results in an increased risk of RIM. Analysis of the dose volume histograms and the corresponding TCP, NTCP and the relative risk of RIM may help develop guidelines for IMRT treatment planning in selecting treatment technique, beam energy, beam delivery methods and plan acceptance criteria.

SU-FF-T-385

Tolerance Levels for Dosimetric IMRT QA Based On Radiobiological Parameters

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Purpose: Tolerance levels for dosimetric verification of IMRT plans are usually set at constant values. This QA process is not patient specific. It ignores the potential role of fraction size and treatment site in determining the clinical consequences of an error in dose calculation and/or delivery. The objective of this work is to develop dose tolerance levels for IMRT based on radiobiological parameters. **Method and Materials:** The linear quadratic cell survival model which accounts for the effects of both total dose and fraction size was used. A technique was developed to convert dosimetric tolerance levels between treatment schedules while maintaining a constant uncertainty in a radiobiological parameter. Specifically, a constant tolerance level in a radiobiological parameter is set, rather than in calculated/delivered dose. Calculations were performed for different treatment fractionations and α/β ratios mimicking a wide range of clinical situations. **Results:** Tumors with low α/β ratio (melanoma, prostate) are more sensitive to errors in total dose. Dosimetric tolerance for such tumors should be approximately 65% of those of other tumors. For such malignances, if a 3% error in calculated/delivered dose is acceptable for treatment of most tumors, this should be reduced to 2% for treatment of these more radiosensitive tumors. In addition, results show that in field late and early responding normal tissues are more sensitive to errors in dose than out of field tissues. **Conclusion:** Invariant tolerance levels are appropriate for a wide range of clinical IMRT schemes, especially given current uncertainties in clinical α/β values. Assuming that current dosimetric levels are appropriate for some clinical applications, the appropriate values are for all other applications are between 0.5-2 times the currently used values for IMRT QA. In conclusion, tolerance levels for dosimetric QA based on radiobiological parameters provide useful information and may be more appropriate for verifying calculated/delivered dose.

SU-FF-T-386

Treatment Optimization for Prostate IMRT Incorporating Utility Analysis and Patient Decisions

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Purpose: Radiation target dose, target margin, and the doses to the surrounding normal tissues are traditionally applied in a standard way (e.g., 76-78Gy to patients with intermediate to high risk prostate cancer). The hypothesis here is that quality of life will be improved on an individual basis by allowing these aspects to vary, within limits, based on the preferences of a given patient in terms of local control and normal tissue toxicities. The goal is to develop planning methods for incorporating utilities. **Method and Materials:** Patient utilities are individual valuations of various health states. Through the incorporation of utilities in the IMRT planning process, the treatment may be tailored to the individual patient desires. The assessment of utilities is ongoing. In this study, DVHs for the target and critical organs are used to estimate tumor control and normal tissue complications and then converted to utility scores. We included utility assessment for baseline general health, and urinary, sexual, and bowel functions. Preliminary results are based on multiple IMRT plans using a commercial TPS. An automated planning process is being developed using a home-grown optimization system. **Results:** Outcome data from the literature and our own institution are used to establish a consistent DVH-utility conversion system. Although such a scoring system is based on the mean values of a patient population the changes in the utility scores for a particular patient are relative and relevant based on the

dosimetric changes in the treatment plans. Emphasis is given to dose in the target, rectum, bladder and erectile tissue to maintain the balance between local control, rectal/bladder bleeding, urinary functions and impotence. Patients are given the opportunity to make treatment decisions by selecting personalized utility criteria. **Conclusion:** Treatment optimization based on utility analysis allows both the oncologist and patient to make personalized treatment decisions.

SU-FF-T-387

Treatment Plan Evaluation and Optimization For SRS and IMRT Using Dose-Surface Histograms

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Purpose: To introduce a new method in determination of the periphery dose and dose differences between the tumor and surrounding tissues, including organs at risk (OARs), for stereotactic radiosurgery (SRS) and/or intensity modulation radiotherapy (IMRT) using dose-surface histograms (DSHs). **Method and Materials:** Plan-target volume (PTV) and its expansion into surrounding healthy tissue (TISSUE) by 3 mm (or 5 mm) for a small (or large) PTV are created. The contours of the TISSUE on CT or MRI slices are modified at the region where the Tissue intersects with an OAR. The PTV and TISSUE are then expanded or shrunk, denoted as PTV' and TISSUE', by a pixel size (PS) within a fine dose grid, respectively. DSH for the PTV (DSH_{PTV}) can then be determined by (DVH_{PTV}*PTV - $DVH_{PTV'}$*PTV')/(PTV – PTV')/PS. Similarly, DSH for the TISSUE (DSH_{TISSUE}) is given by (DVH_{TISSUE}*Tissue - $DVH_{TISSUE'}$*TISSUE')/(TISSUE – TISSUE')/PS. The mean and variation of DSH_{PTV} characterizes the periphery doses and the difference between the mean doses on DSH_{PTV} and DSH_{VOI} quantifies the dose drop-off from the PTV to the surrounding tissue. **Results:** Application of the new method on Gamma Knife plans and LINEAC-based SRS plans clearly shows that gamma knife plan has better dose drop-off but worse periphery doses for relative rounded target. However, the LINEAC-based MLC-shaped arcs plans are generally superior for irregular-shape lesions. In comparison of plans using MLC-shaped arcs, conformal beams, and IMRT, we found no improvement on periphery dose and dose drop-off in IMRT for some cases due to lack of DSH_{PTV} in the inverse planning systems. **Conclusion:** The accurate quantification of the periphery dose and dose drop-off is extremely important because they are closely correlated to the treatment prescription and the clinical outcomes.

SU-FF-T-388

A Method for Repositioning of Stereotactic Brain Patients with the Aid of Real-Time CT Image Guidance

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Purpose: Fractionated stereotactic radiotherapy to the brain is usually delivered using relocatable head frames. Previous studies suggest that with the GTC relocatable frame the position of the patient can be reproduced with uncertainties on the order of 1 to 2 mm. However, the reproducibility of the frame varies from patient to patient and can be poor especially in edentulous patients. The goal of this study was to develop and evaluate a method that recalculates the coordinates of the isocenter for patients undergoing stereotactic treatment to the brain with the GTC relocatable head frame, based on a pre-treatment CT scan. **Method and Materials:** The pre-treatment CT scans were acquired with the Primatom CT-on-rails system (Siemens) and they were fused with the planning scan using the XKnife treatment planning system (Radionics). Then the BRW coordinates of the beam isocenter were recalculated using 3D CT-to-CT image registration provided by the planning system, and a 3D CT-to-BRW coordinate transformation.

The method was evaluated by comparing the initial BRW coordinates of the isocenter with the recalculated coordinates for eight single-fraction patients (64 points). These patients had the BRW frame fixed to the outer table of the skull, and therefore the coordinates compared between the simulation and the pre-treatment scan should be identical. Any difference between the two sets of coordinates was attributed to errors in the method. **Results:** The results showed that the systematic errors in the recalculated coordinates for the BRW frame were lower than 0.05 mm in all three directions, and they were not statistically significant. The random errors (one standard deviation) were from 0.35 mm (lateral) to 0.58 mm (vertical). The average value of the combined 3D difference was 0.75 mm. **Conclusion:** These results suggest that the proposed technique could be used to reduce spatial uncertainties associated with the GTC head frame.

SU-FF-T-389

A Method to Treat GammaKnife Shots Otherwise Untreatable Due to Collison

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Purpose: To develop a technique enabling Gamma Knife shots deemed untreatable because of collision to be delivered using an appropriately shifted stereotactic frame placement without requiring re-imaging of the patient. **Method and Materials:** A Leksell stereotactic frame with a CT fiducial box was applied to a head phantom. The assembly was imaged (1 mm slice thickness), allowing localization of its stereotactic space. Using GammaPlan, the (x,y,z) coordinates of the centers of four 0.5-mm diameter steel spheres positioned as targets within the frontal, temporal, and occipital regions of the head phantom were recorded. A Leksell biopsy arc was then attached to the stereotactic frame and the (r,θ,φ) coordinates of 6 points marked on the phantom surface were recorded. The stereotactic frame was removed from the phantom and re-attached in a different position. The biopsy arc was then used to determine the new (r,θ,φ) coordinates of the same surface points. A transformation algorithm using the two sets of (r,θ,φ) coordinates was applied to the (x,y,z) coordinates of the steel spheres in the original stereotactic space to determine the corresponding coordinates in the second stereotactic space. To test algorithm accuracy, a repeat CT-scan of the phantom was done and the actual (x,y,z) coordinates of the targets in the second stereotactic space were found. **Results**: The mean distance between the algorithm-predicted value and actual value of the target coordinates in the second frame placement was 1.03 (σ = 0.3) mm, demonstrating acceptable accuracy in most clinical situations. **Conclusion:** This technique may be used for treating patients with multiple lesions where collisions prevent treatment with a single frame application. Once all treatable shots are delivered, the frame is shifted and a transformation based on the spherical coordinates of surface points is applied to the untreatable shots which are then delivered in the new stereotactic space. Re-imaging is not necessary.

SU-FF-T-390

A New Linac QA Procedure for the Characterization of Radiation Isocenter and Room Lasers Position

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Purpose: We have designed and implemented a new stereotactic machine QA test. The method is used to characterize gantry sag, couch wobble, cone placement, MLC offset and room lasers position relative to radiation isocenter. An image containing a series of test patterns is generated in a direct and integrated fashion. **Method and Materials:** Two MLC star patterns, a cone pattern and the laser lines are recorded on the same imaging medium, enabling 0.1 mm accuracy measurements. Phosphor plates are used as the imaging medium due to their unique property that the red light of wall laser erases the radiation information stored on phosphor plates. The room lasers position relative to the radiation isocenter can be measured.

The developed QA method consists of four images that measure the gantry sag between 0^0 and 180^0 gantry angles, the position and stability of couch rotational axis, the sag between 90^0 and 270^0 gantry angles, the accuracy of cone placement on the collimator and the position of laser lines relative radiation isocenter. **Results:** The inherent precision of the numerical algorithms developed is +/- 0.05mm. The inherent accuracy of the method as a whole is +/- 0.1mm. The total irradiation/illumination time is about 10 min per image. Automating the generation of collimator star patterns can reduce this time. The data analysis (including the phosphor plate scanning) is less than 5min. **Conclusion:** The presented method reproducibly characterizes the radiation isocenter geometry with the high accuracy required for stereotactic surgery. It can replace the standard ball test and it can provide a highly accurate QA procedure for the non-stereotactic machines.

SU-FF-T-391

A New Look at Helmet Output Factor Utility in Gamma Knife Treatments

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Purpose: To characterize the volume dose distribution of Gamma Knife (GK) stereotactic radiosurgery units to compare point-measurement based helmet factors and volume-based measurements of dose. **Method and Materials:** Helmet factors were determined using radiochromic film and ionization chamber measurements as well as TLD arrays. Novel methods have been used to determine and characterize the volume of dose delivered by the GK unit. These methods include using large volume ionization chambers and deconvolving the measurement to remove volume averaging effects and creating a film phantom that allows us to map the entire dose volume in 3 dimensions by using cubes of radiochromic film. **Results:** The preliminary work done using traditional methods to determine helmet factors has shown that a single point measurement may be insufficient when delivering doses of the magnitude seen in GK treatments. Analysis using TLDs and radiochromic film indicate that non-uniform dose distributions exist. It has also been shown that the isocenter of the GK does not always correspond with the point of maximum dose. Additionally, helmet factor determination is dependent on the size of the dosimeter being used, thus larger dosimeters demonstrate volume averaging effects preventing the proper determination of helmet factors. **Conclusion:** GK treatment is the preferred modality for a number of cranial treatments, and physicians are continually prescribing smaller margins. For this reason, it is vital that the dosimetry of the GK be representative of what the patient receives. While point and plane dosimetry techniques may be adequate when delivering radiation from one direction, 3-D techniques must be developed for modalities like the GK, in which dose is delivered with multiple sources simultaneously and almost isotropically.

SU-FF-T-392

A Technique for Non-Coplanar Helical Tomotherapy Cranial Radiosurgery Treatment

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Purpose: To demonstrate a new technique for non-coplanar helical Tomotherapy cranial radiosurgery treatment. Evaluation of the improvement, in terms of minimizing the dose to healthy tissue, of the non-coplanar technique over the conventional coplanar treatment. **Methods & Materials:** The proposed technique for non-coplanar helical Tomotherapy cranial radiosurgery is demonstrated using an anthropomorphic phantom (Rando phantom). Obtaining a composite dose distribution of the optimized non-coplanar plans is not possible with the current helical Tomotherapy planning system. For comparison of the dose coverage, conformality and dose volumes between the non-coplanar and the conventional coplanar treatment techniques, film dosimetry is used to obtain isodose distributions. A calibrated Welhofer scanner was utilized for the film dosimetry. **Results:** The results show significant reduction in the volumes receiving 60% or less of the prescribed dose. There is no appreciable change in volumes receiving 70% or more of the prescribed dose. Dose volume ratios, DV20/80and DV30/70 (defined as the ratio of the volumes receiving 20% and 80%, and the ratio of volumes receiving 30% and 70% of the prescribed dose, respectively) are used to quantify the improvement of a non-coplanar helical Tomotherapy cranial radiosurgery technique. The DV20/80 and DV30/70 dose volume ratios obtained for the non-coplanar technique are 9.33 and 4.57, respectively, whereas ratios obtained for the standard coplanar technique are 11.33 and 5.01, respectively. **Conclusion:** The results of the study clearly demonstrate that the dose to healthy tissue can be minimized by using three non-coplanar angular orientations for helical Tomotherapy cranial radiosurgery. More marked improvements can be obtained by utilizing more than three non-coplanar angles, but at a high cost in terms of planning and treatment times. Balancing the improvements in DV20/80 and DV30/70 ratios and the required treatment and planning times entails making proper clinical judgment for each case.

SU-FF-T-393

An Anthropomorphic Phantom for Respiratory Motion Research in Dynamic SRS

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Purpose: The purpose of our experiment is to study the use of a respiratory anthropomorphic phantom evaluating the respiratory motion tracking capabilities in dynamic stereotactic radiosurgery (SRS). **Method and Materials:** An anthropomorphic phantom was scanned with 1.25 mm slice spacing on a 4-slice GE Lightspeed CT. A Harvard lung pump was attached to the lung bellows of the phantom and set to 15 breath/min, 40% expiration. The abdominal cavity was filled with humid sponges to resemble lung tissue density. A mini-ballcube containing a pair of orthogonal GaF-chromic films was attached to the diaphragm. The spherical target was treated to 3000cGy at 100% isodose line using both a static SRS and dynamic SRS (Synchrony) treatment. The films were analyzed using a Vidar VXR-16 scanner and the Accuray film analysis tool.. **Results:** CT numbers measured in the phantom range from 42-162 for the sponges, 1111-1193 for the silicone tissue, and 1412 – 1512 for the embedded plastic skeleton. The total targeting error for the diaphragm treatment was 0.77 mm in the static and 0.91 in the dynamic case. The eccentricity for the spherical target was 1.27 mm in the axial plane for both treatments, and 1.34 mm for the static and 1.41 mm for the dynamic treatment in the coronal plane. The respiratory pattern was very similar to patterns observed in Synchrony patients. The extent of diaphragmatic motion was 8-10 mm in the superior/inferior direction. **Conclusion**: The respiratory anthropomorphic phantom is a promising tool for evaluating the respiratory motion tracking capabilities of dynamic SRS in a patient-like environment. The accessible abdominal cavity allows for different target positions. It can easily be filled with different materials (sponges, saline solution, organic material, gels) to simulate different environments in the body. The electron densities (CT numbers) of the phantom material are very close to human tissue.

SU-FF-T-394

An Image Guided Target Localization System for Brain Radiosurgery and Fractionated Stereotactic Radiotherapy Using a Non-Invasive Fixation

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Purpose: To develop an image guided target localization technique to improve the patient positioning accuracy for brain radiosurgery and fractionated stereotactic radiotherapy using non-invasive fixation. **Materials and method:** BrainLab stereotactic localization box system is used for the initial patient setup. The patient is immobilized using a thermal mask with a mouth bite piece. An image guided localization system (Novalis body system, BrainLab) is used to finely adjust the position after the initial setup. The system automatically fuses two X-ray images with the corresponding DRR and gives the position offsets in 6 dimensions. The accuracy of the image guided localization system was evaluated in a rando phantom with a 2-mm-metal-ball placed as the isocenter, and in15 patients with total of 48 fractions for image fusion. **Results:** The phantom study showed that the positioning accuracy is within 1-mm for various isocenter positions. The image fusion for each patient was checked carefully and could be evaluated easily due to its rigid structure and rich bony features. At least three distinguish features could be identified in each image, and a 1-mm translational move generally induced a visible dis-matching in these features. This suggests that the accuracy of alignment to the isocenter of the X-ray system be better than 1-mm. Considering that the isocenter of the X-ray system could be different from the linac's, the overall positioning accuracy for the image guided system would be in the order of 1.4-mm. The offsets of the fusion results was used for mutual testing between the image guided system and the stereotactic localization box system. The average offsets for the lateral, AP and longitudinal directions were -0.67±1.09, 0.44±1.09, and –0.84±1.44 mm, respectively. This is consistent with the results of the non-invasive immobilization techniques reported by

other authors. **Conclusion:** The image guided system could improve the patient positioning accuracy.

SU-FF-T-395

An Integrated GRID Boost Technique for Gamma Knife Radiosurgery

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Purpose: To develop an integrated boost approach with the GRID technique for Gamma Knife radiosurgery **Method and Materials:** The GRID technique was originally developed for external beam radiation therapy where a high dose being delivered via a multi-hole collimator. The goal of the technique is to debulk large tumor with spatially fractionated dose distributions. In this study, we developed an integrated GRID boost approach for Gamma Knife radiosurgery where an array of high dose areas was placed inside the target volume using a series of 4-mm shots. The dose grid was added on top of the existing dose distributions where a peripheral isodose line (e.g. 50%) covers the full target volume. We optimized the weights of the 4-mm shots to equalize the integral dose at each shot location. Treatment plans were developed and evaluated based on peripheral dose fall-off and dose to normal brain as compared with the conventional Gamma Knife treatment plans. The comparison was also performed using equivalent uniform dose (EUD), tumor control probabilities (TCP), and normal tissue complication probabilities (NTCP). **Results:** All parameters for the target volume (mean dose, EUD, and TCP) increased significantly (> 5-30%) for the GRID boost technique as compared with the conventional Gamma Knife plans. The peripheral isodose coverage of the target volume (as measured with conformity index) remained unchanged for the GRID boost technique. In contrast, the EUD and the NTCP for the normal brain tissue adjacent to the target decreased significantly (as much as 40% in NTCP) for the GRID boost plans. Slightly faster dose fall-off near the peripheral target region was noted for the GRID delivery. **Conclusion:** We demonstrated a new GRID technique for Gamma Knife radiosurgery in escalating the dose to the target volume while improving adjacent normal brain sparing.

SU-FF-T-396

Analytical Derivation of 6 MV Radiosurgery Cone Factors

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Purpose: To derive cone factors analytically for 6 MV radiosurgery beams **Method and Materials:** Lack of lateral electronic equilibrium and finite detector size make experimental measurements of stereotactic radiosurgery cone factors a difficult task. In this work, cone factors for 6 MV radiosurgery beams of various cross sections are determined using an analytical model for absorbed dose in narrow photon beams and validated by means of experimental measurements in water. The model allows one to calculate absorbed dose under electronic disequilibrium conditions using measured broad-beam data. For each cone ranging from 4 mm to 20 mm in diameter, cone factor is derived analytically and compared to that measured in water experimentally using a high resolution diode and a computerized data acquisition system. **Results:** The agreement between the analytical and measured cone factors is within 2.5 % of local value. **Conclusion:** Based on the results of this study for 6 MV x-rays, the analytical method described here can be employed to determine radiosurgery cone factors. It provides a viable alternative to experimental methods where measurements in water are arduous. It can be used as an independent method or to validate experimental results

SU-FF-T-397

Characteristics of a Double-Focused µMLC

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Purpose: Micro multi-leaf collimators (µMLC) are widely used as add-on to linear accelerators for the generation of small irregular shaped beams. The purpose of this paper is to measure the dosimetric characteristics of a double-focused µMLC. The dose field generated by a double-focused µMLC has a steep dose gradient at all field edges and is therefore able to spare the healthy tissue better than a single-focused µMLC **Method and Materials:** At our department we have mounted a double-focused µMLC on a Siemens Primus linear accelerator. Base on the separate gantry sensor, this µMLC is independent from the type or manufacturer of the linac. The basic dosimetric properties, such as transmission or leakage, depth-dose curves and penumbra, have been measured by use of radiographic and radiochromic films, pinpoint ionization chambers and our multi-purpose QA-Phantom (Easy Cube). **Results:** Transmission and leakage between the leaves are due to their special focusing design very low. The depth doses distributions for different field sizes generated by the µMLC are identical to the depth doses for the same field sizes generated by the MLC integrated in the linac. Therefore the µMLC affects only the off-axis ratio. Due to the double-focusing characteristics the penumbra is small and identical for the field length and width. The penumbra gradient does not differ significantly with different field sizes. **Conclusion:** The mechanical investigations show that the µMLC can securely be used with a Siemens Primus linear accelerator. The measured dosimetric properties show a small penumbra that is identical in both directions (inplane and crossplane). This is important if the µMLC is applied for stereotactic and intensity modulated radiotherapy.

SU-FF-T-398

Commissioning a 5 Mm Circular Cone for Linac-Based Stereotactic Radiosurgery Using MicroMOSFET and Polymer Gel

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Purpose: The accuracy of measured small cone parameters is important in the treatment of certain disorders like trigeminal neuralgia, where a single large dose is delivered via a small cone. The purpose of this presentation is to identify practical dosimeters for commissioning the cone accurately and efficiently in a community clinic. **Method and Materials:** Relative output factors for 5, 12.5, and 15 mm cones were measured using microMOSFET, Kodak EDR2 film, and TLD microcubes. TMRs for the 5 mm cone were measured using microMOSFET and BANG®polymer gel. OARs for the 5 mm cone were measured using radiographic and radiochromic films. **Results:** The output factor for the 5 mm cone measured with microMOSFET was 0.654 for a 6 MV beam and agreed with data published elsewhere. MicroMOSFET measurements agreed with EDR2 film and TLD microcubes measurements within 4.3% and 3.2% respectively for the 5 mm cone. All techniques were within 2.5% agreement for the 12.5 and 15 mm cones. TMR values measured with microMOSFET and polymer gel agreed within 3%. Radiographic and radiochromic film off-axis ratio measurements showed differences not exceeding 1% above the 10% relative dose level. The measurements were verified using a MD Anderson Cancer Center phantom for a single static beam and polymer gel for a clinical set of three arcs. The doses reported by the institution and MDACC at dmax and 7.5 cm depth agreed within 4% and 3% respectively. The volumetric doses between the treatment planning system and the polymer gel were within 4%. **Conclusion:** The overall precision and accuracy of microMOSFET-based measurement techniques are clinically acceptable. The microMOSFET is a feasible alternative with some advantages to TLD microcubes for dosimetric measurements of very small cones and fields. The polymer gel was found to be the only commercially available 3D-dimensional verification dosimeter for these cones.

SU-FF-T-399

Comparison of Stochastic and Analytical Algorithms in Selecting Gamma Knife Plug Patterns for Treatment Planning

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Purpose: In gamma knife SRS, plugging pattern is often used to decrease dose to critical structure. Two algorithms have been developed and analyzed in this study. One is the stochastic plug selection based on simulated annealing algorithm; the other is the analytical approach based on greedy algorithm. Clinical cases were implemented to compare the efficiency of these two algorithms. **Method and Materials:** With the gamma knife analytical model, the target volume and the critical structure contours were extracted from the Leksell Gamma knife Plan. We used the integral dose to the critical structure as the objective function. This objective function is calculated by adding each plug's dose contribution to

the structure. For simulated annealing algorithm, the energy term is the objective function, by randomly selecting blocked pattern from a randomly generated plugging pattern pool. By controlling iteration number, simulated annealing algorithm produced an optimal blocked pattern with optimal energy term. The greedy search approach also produced the optimal objective function value based on the dose contribution order from different plugs. The values from the objective function and the DVH are compared to show the performance of these two algorithms. **Results:** A number of different objective function values are computed via simulated annealing algorithm. We found that the objective function value is generally smaller than the objective function value attained by greedy approach. And the DVH also shows that simulated annealing algorithm gives less effective result to satisfy the criteria to deliver smaller dose to critical structure. **Conclusion:** The greedy approach produces an optimal blocked pattern in the first order with the objective function, and the solution is generally better than the simulated annealing algorithm. In addition, the simulated annealing algorithm demands long computational time and the more fluctuations in the final results.

SU-FF-T-400

Computational Study of the Rigid Body Image Registration Accuracy

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Purpose: To study, using a computational simulation, the accuracy of the rigid body based image registration of the brain with special considerations for the type of the distribution of the homologous fiducial points used in the registration. To determine how the registration affects the resultant accuracy for target points. **Method and Materials:** The condition numbers of all the combinations of at least four out of the 25 candidate fiducial points are examined. This yields the sets of points with the best and the worst condition number. The Gaussian noise is imposed on the simulation points. The algorithms' accuracy for the sought rotation matrix and the translation, fiducial registration error (FRE), and target registration error (TRE) are investigated as a function of the number of fiducial points used in the registration

Three different algorithms are used: SVD based, the subspace method for the translation computation and the simultaneous optimization of the Euler angles and translation. **Results and Conclusion:** The robustness of all the algorithms is similar. For the lower number of fiducial points there is a risk of big TREs. Thus the condition number reveals a bad prospective input for the algorithm. The number of points needed to reach 1.0 mm accuracy for 0.5x0.5x1.0 mm^3 pixel size should be six points or more. This method of the condition number examination can be used to predetermine the accuracy of the registration for a given input.

SU-FF-T-401

Development of Specific Treatment Plan Based On Physical Lattice Structure for Stereotactic Radiosurgery

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Purpose: The stereotactic radiosurgery (SRS) describes a method of delivering a high dose of radiation to a small target volume in the brain, generally in a single fraction, while the dose delivered to the surrounding normal tissue should be minimized. To perform automatic plan of the SRS, a new method of multi-isocenter/shot linear accelerator (linac) and gamma knife (GK) radiosurgery treatment plan was developed, based on a physical lattice structure in target. **Method and Materials:** The optimal radiosurgical plan had constructed by many beam parameters in a linear accelerator or gamma knife-based radiation therapy. In this work, one isocenter/shot was modeled as a sphere, which is equal to the circular collimator/helmet hole size because the dimension of the 50% isodose level in the dose profile is similar to its size. In computer-aided system, it accomplished first an automatic arrangement of multi-isocenter/shot considering two parameters such as positions and collimator/helmet sizes for each isocenter/shot. Simultaneously, an irregularly shaped target was approximated by cubic structures through computation of voxel units. The treatment planning method by the technique was evaluated as a dose distribution by dose volume histograms (DVHs), dose conformity, and dose homogeneity to targets. **Results:** For irregularly shaped targets, the new method performed the optimal multi-isocenter packing, and it only took a few seconds in computer-aided system. The targets were included in a more than 50% isodose curve. The dose conformity was ordinarily acceptable levels and the dose homogeneity was always less than 2.0, satisfying for various targets referred to Radiation Therapy Oncology Group (RTOG) SRS criteria. **Conclusion:** This approach using new method could be an efficient radiosurgical plan used two beam parameters both the irregularly shaped targets and different modality techniques such as linac and GK for SRS.

SU-FF-T-402

Dosimetric Comparison of Different MLC Systems for IMSRT

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Purpose: To compare different MLC systems for intensity modulated stereotactic radiotherapy (IMSRT) of intracranial tumours with different sizes and complexities. **Method and Materials:** Radionics treatment planning and delivery systems, including a Mini Multileaf Collimator (MMLC) are routinely used at our institution for stereotactic radiotherapy of intracranial lesions. A Varian Millennium MLC has also been commissioned to eliminate the maximum field size limitation (10x12 cm) of MMLC. The two MLC systems have different dosimetric parameters, mainly due to different leaf thicknesses and isocentric distances. In this work we explore the effects of these differences on IMSRT of intracranial tumours. Radionics treatment planning system (XK-RT3) is used for planning 3 clinical cases in this study. Identical beam arrangement and optimisation parameters were chosen for the two systems. Comparison parameters include: 2D and 3D dose distributions, dose heterogeneity (DH), maximum, minimum and median doses as well as dose volume histograms (DVH) for the target volume; and maximum dose, median dose, dose of 10%, 20% and 50% volumes (D_{10}, D_{20} and D_{50}) and DVHs for the OAR. The OAR dose volume data are presented for a normalised dose, when 95% of the tumour received at least 95% of the prescribed dose. **Results:** DVH data have shown that the two systems are overall comparable in terms of tumour dose coverage. However, Radionics MMLC had the advantage of delivering the prescribed doses using fewer segments and less number of monitor units by up to 35% and 48%, respectively and therefore less dose to the surrounding normal structures and better sparing of OARs by up to 7%. **Conclusion:** In this work we have shown that the two MLC systems are overall clinically comparable, with Radionics MMLC marginally better sparing normal tissues. The Varian MLC however has the advantage of larger field size and better isocentric clearance.

SU-FF-T-403

Evaluation of Doses Delivered by SBRT to the Lung of An Anthropomorphic Thorax Phantom

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Purpose: Evaluation of SBRT through the use of a thorax phantom. **Method and Materials:** A new protocol evaluates stereotactic body radiation therapy for patients with lung cancer. Institutions must be credentialed before enrolling patients. Successful irradiation of a thorax phantom is one of the steps. The thorax phantom is a plastic shell incorporating structures that represent the spinal cord, the heart and the lungs. A structure representing a tumor is positioned in the left lung. TLDs and radiochromic films measure the delivered dose distribution. Institutions were instructed to image the phantom, plan a treatment following specific constraints and deliver the treatment as if to a patient. The measured dose distributions were compared to the institutions' calculated isodose distributions. **Results:** Institutions were instructed to deliver a treatment calculated without heterogeneity corrections and submit both corrected and uncorrected isodose distributions. Results from seven institutions established a baseline for this test. The average of the ratio between measured and calculated target dose was 0.97 ± 3% with corrections on and 1.14 ± 3% with corrections off. The displacement between measured and calculated dose distributions in the vicinity of the target did not exceed 5 mm. **Conclusion:** Criteria for the evaluation of this test were defined for heterogeneity-corrected dose calculations. A range of 0.97 ± 7% was established for the ratio of measured and calculated

target doses. A maximum of 5 mm displacement between the calculated dose distribution and the film profile was considered acceptable. Additional criteria are under consideration. This work was supported by PHS grants CA 10953 and CA 81647 awarded by NCI, DHHS.

SU-FF-T-404

Fractionated Radiosurgery by Adaptation of Resources

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Purpose: Our goal was to integrate broadly accessible, multi-purpose tools to form a system for non-invasive MLC-based fractionated radiosurgery. We investigated the use of a Varian Millennium MLC (mMLC, 5mm-leaf resolution) in conjunction with an aSi electronic portal imaging device (EPID) and Varian ZMed RadioCamera system for this purpose. **Method and Materials:** Pinpoint and RK chambers were used to measure data from small fields (mMLC shaped). Profiles for field sizes ranging from 4x4 to 1x1-cm were measured in water, while output measurements were taken in a MedTec IMRT phantom. These data were used to commission an mMLC radiosurgery (fRS) beam in Theraplan Plus v3.8. Dose distributions created with this beam were compared both to measurement and circular collimator-based SRS distributions. The RadioCamera system consists of an infrared camera and customized biteblock equipped with infrared markers. This detects motion in real time and allows the beam to be halted when a threshold is reached. The radio-opaque markers are also used as a fiducial system for EPID. The motion sensitivity threshold and consistency of the biteblock-mounted fiducials were both examined. Finally, the full system was tested using a film phantom outfitted with a biteblock. **Results:** Planning system predictions using the fRS beam match measured profiles, depth doses and output factors. Plans created with this beam were shown to approach those created using radiosurgery cones, based on DVH, homogeneity and conformity analyses. The IR camera system is sensitive to 0.2mm motion in all directions. Overall system test indicated that we can treat 1cm lesions with 0.3cm PTV and MLC margins. **Conclusion:** Our studies indicate that the combination of mMLC, infrared motion tracking, and EPID verification is sufficient to form a practical system for non-invasive, fractionated radiosurgery, comparable to conventional linac-based radiosurgery. This system is being used clinically at our institution.

SU-FF-T-405

Impact of Tissue Heterogeneities Upon Dose Delivery to Lung Lesions and Comparison of BrainSCAN Treatment Planning System Dose Calculations

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Purpose: Tissue heterogeneity changes result in a build down/build up of the recoil electron fluence at heterogeneity interfaces. The use of stereotactic radiosurgery beams on small lung lesions can compromise the dose delivery to lesions ranging from 6 mm up through 30 mm in diameter, since the dimensions of the lesions are comparable to the range of the secondary electrons in lung and air. Dose perturbations are evaluated for a range of lesion diameters in lung equivalent phantom material. **Method and Materials:** Lesion diameters of 6.4, 12.5, 19.7, and 25.4 mm of unit density were inserted into lung equivalent material. The dose distributions were measured with film densitometry and calculated with the dose calculation engine of the ADAC Pinnacle system. The Pinnacle treatment planning system uses the adaptive convolution superposition algorithm, which rigorously reproduces x-ray beam attenuation, and the electron fluence changes at tissue heterogeneity interfaces. **Results:** The physical density of the lung equivalent phantom material is 0.30 g/cm^3 in contrast to water and normal tissue at 1.0 g/cm^3. The spherical tumor phantoms were irradiated with beam margins of 0, 7, 10, and 25 mm. Dose volume histogram analysis was performed to develop a DVH surface map of the dose delivery to each lesion as a function of margin size. It was determined that a 7 mm margin for all lesion diameters delivers a minimum tumor dose of 94 % of the prescribed isocenter dose for all lesion diameters. The DVH analysis and film dosimetry were also compared with the dose calculations of the BrainSCAN planning system. **Conclusion:** These measurements and calculations confirm the clinical feasibility of stereotactic irradiations of lung lesions with minimal compromise of the tumor dose.

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SU-FF-T-406

Measured Dose Gradients for Extracranial Stereotactic Radiosurgery

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Purpose: The main limiting factor in determining the amount of radiation dose that can be prescribed to a vertebral metastasis is the dose to the spinal cord. The goal of this work was to measure the dose gradient for a helical tomotherapy delivery system. Method and Materials:
The spinal cord organ at risk (OAR) was a cylinder 10-mm in diameter that extended 5-cm superior-inferior. The PTV was a half annulus 25-mm thick that also extended 5-cm superior-inferior. Five benchmark test cases were created with the separation between the PTV and the spinal cord set to 2-mm, 4-mm, 6-mm, 8-mm, and 10-mm. Although the gap between the PTV and the OAR was variable, the thickness of the PTV was held constant. Relative dose measurements were made using calibrated film placed in the phantom. The dose gradient was measured from the slope of anterior-posterior profiles in the gap region between the PTV and the OAR.. **Results:** For a 10-mm gap, the calculated maximum OAR dose was 7.5 Gy (25%) for a prescribed PTV dose of 30 Gy. The calculated maximum OAR dose increased to 21.3 Gy (71%) with a separation of 2-mm. A linear regression yielded a dose gradient of 10.6% / mm ($R^2 = 0.988$). Typically, dose gradients in excess of 5% / mm decrease the PTV uniformity index below the clinically acceptable 20%. However, the benchmark tests in this study yielded a dose gradient in excess of 10% / mm while maintaining PTV uniformity indices of 4, 10, 11, 11, and 11% respectively for the 10, 8, 6, 4, and 2-mm PTV-to-OAR separations. **Conclusion:** Helical tomotherapy benchmark test cases delivered to a cylindrical phantom indicated that the delivered dose gradient could be as high as 10% per millimeter while providing PTV uniformity of 15% or less.

SU-FF-T-407

Prediction and Optimization of Stereo Tactic Frame Placement for Collision Avoidance in Gamma Knife Radio Surgery

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Purpose: To develop a positioning assistive device (PAD) and system that optimizes the use of gamma knife stereo tactic frame placement before treatment in avoiding frame-collimator collisions during treatment. **Method and Materials:** Prior to stereo tactic frame application, pretreatment MRI or CT images are used for tumor localization. The PAD system has been designed and constructed to predict the optimal frame placement coordinates. The PAD device is used to assist in applying the stereo tactic frame, utilizing optimized frame placement coordinates, with respect to a fiducial marker placed on a phantom prior to scanning.
The PAD device has been constructed using high grade plastic curved to accommodate a cervical collar on its inner surface and a steel block and rod system to its outer surface. The block and rod system consists of a horizontal (y-axis) and a vertical (z-axis) rod with a 90 degree bend at the top (x-axis). The two rods are attached via a block with two oblique holes each taped with a screw to allow for adjustment along the respective axis. The x-axis portion has a block with a dovetail grove to allow attachment of the stereo tactic frame.
The block and rod system allows for translation and rotation about each axis enabling six degrees of freedom in a compact design. This ensures that the placement of the stereo tactic frame is level and accurate. **Results:** The PAD system has been found to optimize frame placement and predict frame/collimator collisions. PAD allowed for accurate and reproducible frame applications. **Conclusion:** The PAD system will allow the neurosurgeon the ability to apply the stereo tactic frame to the patient in a more accurate and reproducible way. PAD does lead to easier treatment planning, faster treatment delivery, and reduced patient stress. Demonstration of the device will be presented.

SU-FF-T-408

Regular Lesions Stereotactic Treatment:Physical and Dosimetrical Comparison Between Circular and Mini/micro Multileaf Collimators
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Purpose: The comparison of stereotactic treatments for small spherical and ellipsoidal intracranial lesions using three different collimators with single isocenter: the standard circular collimators and two dynamic multileaf collimators (DMLC) with 3 mm and 5 mm leaf thickness, micro and mini DMLC respectively. **Method and Materials:** Spherical and ellipsoidal lesions of different sizes were designed to evaluate treatments with collimators under consideration. For spherical lesions with diameter from 15 mm up to 35 mm a treatment with 9 arcs of 140 degrees was performed. For ellipsoidal lesions treated with circular collimators, different combinations of treatment variables were studied to achieve 80% isodose surface conformation: number of arcs, gantry start/stop angles, couch angles and arc spacing. This treatment was matched up to 9 arcs with the two DMLCs. For the comparison geometrical (penumbra, difference between the target volume and 80% isodose volume and conformal indexes) and radiobiological (EUD, TCP and NTCP) parameters were used. **Results:** Circular collimators and micro DMLC behave similarly with spherical targets in terms of conformal indexes and TCP/NTCP, but EUD and 20% isodose volume are greater for micro DMLC.
In the case of ellipsoidal target TCP/NTCP are comparable, EUD is greater for micro DMLC but conformal indexes are higher for circular collimators. The 20% isodose volume is less with micro DMLC; the difference, however, is entirely due to the wider penumbra along the deformation axis with circular collimators. The same considerations are valid for targets with diameters $\geq$ 35 mm, where mini DMLC becomes competitive versus circular collimator. **Conclusion:** The analysis shows that micro and mini DMLC are more functional for non spherical lesions. Circular collimators however are widely used and yield sharper dose fall off along directions perpendicular to the deformation axis and thus are preferable in the case of neighbourhood of organs at risk.

SU-FF-T-409

Study of the Technology of Pin-Point CT Imaging Guide System
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Purpose: The Pin-PointTM is a technology for promoting accurate access to a designate target in the CT room, especially during biopsy procedures. This study is to confirm its capability by an independent methodology for clinical implementation. **Method and Materials:** The Pin-Point system (FigA) is based on CT imaging with an invisible frame system and instant 3-D image reconstruction in the laser (needle insertion) plane as illustrated in FigB. Two (yam and daikon) phantoms were used for the studies. The center portion of the phantoms was cut into ten 4mm thick slices. Simulated tumors were created on each slice using barium paste. Organs at risk (OAR) were carved with various shape cavities. BBs were attached as reference points (FigC). Target searching and their correlation to the neighboring OARs were explored. An optimal "reference point R" was defined to serve as navigation for the laser-guided needle for start location, direction, and the needle depth to reach the targets and avoid OARs. **Results:** FigD demonstrates the needle reaching the tumor as navigated by the Pin-Point system. We oriented the guiding laser beam and pushed its path depth from point R to the tumor edge. Next the phantom slices were studied to determine needle positioning relative to the target and OARs, and compared with the foregoing CT image. The agreement is shown in FigD. FigE illustrates the optimal needle trajectory to 'tumor A', by-passing the OARs. FigF illustrates pre-warning of OARs. FigG displays the possibility of excessive needle penetration. **Conclusion:** Pin-Point system was accurate for correct tumor access without jeopardizing the nearby OARs. Our study proves valuable for the search of designated tumors and avoiding critical structures. In addition, its feasibility for further application to linac based stereotactic radiosurgery as frameless setup should be studied.

SU-FF-T-410

Target Localization of Intensity Modulated Radio-Surgery Patients Using ExacTrac System
S Li*, K Ayyangar, S Pillai, R Nehru, A Fung, D Djajaputra, R Thompson, N Raman, W Zhen, C Enke, Univ Nebraska Medical Center, Omaha, NE
Purpose: The Novalis body system, ExacTrac®, was used to verify target localization and to improve patient positioning for daily treatment with patient pre-positioning by mask and head frame in intensity modulated radio-surgery(IMRS). This study is to present preliminary results of quantitative measurements from the ExacTrac system. **Method and Materials:** Accuracy of image fusion and correct calibration of ExacTrac system were investigated using the head section of anthropomorphic phantom. The phantom was randomly moved away from the target position manually and re-positioned using the ExacTrac system. Couch final position was then compared with target position to determine positioning errors. ExacTrac recorded data from 12 patients was used for this study. A verification plan for exporting DRRs to ExacTrac was created for each patient using reference point as localizer. The patient was placed on the couch with mask and isocenter was aligned with target positioner. Two x-ray images were taken and registered to DRRs using automatic 3D fusion. After visual examination of the match of bony structures surrounding the isocenter, the necessary couch movements were performed based on shifts computed from 3D fusion. **Results:** For 7 cranial patients with total 106 treatments, the lateral, longitudinal and vertical average shifts were 0.80, 1.91, and 0.99 mm respectively; for 4 orbital patients with total 103 treatments, the shifts were 0.6, 1.4, and 0.6mm respectively; for one C-spine patient with total 28 treatments, shifts were 1.5, 1.6, and 2.3 mm respectively. According to 11 phantom measurements, our ExacTrac system had accuracy of 0.27, 0.64, and 0.55 mm respectively. **Conclusion:** Target shifts in patient positioning by mask and head frame could be more than 1.0 mm and was larger in longitudinal direction for treatment of cranial and orbital tumors. With x-ray image guidance, ExacTrac system localizes target with accuracy of less than 1.0 mm.

SU-FF-T-411

The Diode Volume Averaging Effect and Corrections in Very Small Photon Fields
E Sham*, S Devic, J Seuntjens, E Podgorsak, McGill Univ Health Center, Montreal, QC, CA

Purpose: To evaluate the volume effect of diode dosimeters. Two p-type silicon diodes, one with a sensitive volume diameter of 0.6 mm (small diode) and the other with a diameter of 2.5 mm (large diode), were used to measure percentage depth doses and profiles of very small 10 MV radiation beams with diameters of 1.5 and 3 mm. Because of the volume averaging effect, responses of the two diodes differ significantly. In this presentation we describe techniques suitable to correct for the volume effect exhibited by the large diode. **Method and Materials:** Volume effect corrections to PDD measurements include: (1) simulating diode measurements by Monte Carlo (MC) technique and determining the central axial geometry factors associated with the diode active areas and (2) changing the measurement setup from SSD to SAD followed by converting the large diode TMR data to PDD with the inverse square law. Volume effect corrections to profile measurements include: (1) applying an inverse gradient algorithm to de-convolve the broadened large diode profile and (2) simulating the diode profiles by film measurements and determining the lateral geometry factors for de-convolution with image analysis of the film. **Results:** For the 1.5 mm field, significant decreases in relative errors between the large diode PDD and the (reference) small diode data are observed after applying either MC correction or TMR conversion. In the 3 mm field at the depth of dose maximum, the inverse and film de-convolution techniques reduce the FWHM of the large diode profile from 3.8 mm to 3.2 mm and 3.0 mm, respectively. **Conclusion:** The correction techniques we apply to large diode data result in reasonable agreement between the large and small diode data, allowing the use of large diodes for PDDs and beam profiles in very small radiation beams.

SU-FF-T-412

The Feasibility of Using Tomotherapy Hi-Art Machine for Stereotactic Radiosurgery
H Jaradat*, W Tome, M Mehta, University of Wisconsin, Madison, WI

Purpose: To study the feasibility of treating multiple-brain metastass with

stereotactic radiosurgery using the tomotherapy Hi-Art machine, and to compare tomotherapy stereotactic radiosurgery treatment plans with conventional linac-based stereotactic radiosurgery plans. **Method and Materials:** Five previously treated patients with multiple brain metastases

ranging from 1 to 5 metastases were selected for the study. These five patients were treated with linac stereotactic radiosurgery. The same structures and prescription doses used for linac radiosurgery were also used to produce stereotactic radiosurgery treatment plans on the tomotherapy planning system. In order to compare the tomotherapy plans to the linac-based plans, the homogeneity of the target volumes, as well as the PITV, the volume of normal brain tissue receiving at least 10Gy and treatment time were considered. **Results:** Analysis of the five plans shows that the target dose uniformity, target dose conformality, and the treatment time for each plan is much improved for tomotherapy. The plans show that on average using tomotherapy planning system increases the dose uniformity by 70%, increases the target-dose conformality by 42% while it reduces the normal tissue volume receiving at least 10 Gy by about 40% for large metastases. On the other hand, for metastases smaller than 1cc tomotherapy increases the 10.0 Gy volume over that for a conventional linac plan by about 60%. **Conclusion:** These results show that tomotherapy could be used for treating patients with multiple brain metastases using stereotactic radiosurgey.

SU-FF-T-413

The Impact of Heterogeneity Correction On Tumor Dosimetry for Lung Cancer Stereotactic Body Radiation Therapy

M Ding*, F Newman, K Stuhr, University of Colorado Health Science Center, Aurora, CO

Purpose: Stereotactic body radiation therapy (SBRT) for non-small cell lung cancer has been shown to limit toxicity. Heterogeneity correction on lung cancer radiotherapy has not been recommended by RTOG. In this study, dosimetric difference between the SBRT plans with/without heterogeneity correction is analyzed. **Method and Materials:** Nine lung cancer patients treated with SBRT techniques using a 6 MV Novalis system were selected. Using the path length algorithm in BrainLAB treatment planning system, all the treatment plans were applied the heterogeneity correction. With same beam parameters, we performed the plans without the heterogeneity correction, and compared the dosimetric difference to the treatment plans. The heterogeneity correction factors (*Kc*) at iso-center, target coverage, heterogeneity index (HI), and conformity index (CI) were used in the comparison. **Results:** The average of Kc at isocenter for 14 planning target volumes (PTV) was 1.002±0.02, only three Kc values (1.07, 0.985, 0.981) were relatively off to the average. Except one case, the other 13 target coverage values of the plans with the heterogeneity correction were better than those without the correction. The maximum difference of the target coverage was ~7%. All the HI values of the plans with the heterogeneity correction were better than those without the correction. The maximum difference of the HI reached 300%. The difference of the CI between the compared plans was within ~10%. The CIs of the plans without correction were better than those corrected. For one case ─ the tumor located in the lung base, the impact of heterogeneity correction was significant. **Conclusion:** The impact of heterogeneity correction for tumor dosimetry on SBRT for lung cancer is case depended. For most primary lung tumors the difference between the plans with/without heterogeneity correction is clinically insignificant. For the tumors near the interface of different mass density, the heterogeneity correction is necessary.

SU-FF-T-414

Transfer of Brain Tumor Patients From Leksell Gamma Knife to BrainLAB Novalis

T Djemil*, J Suh, G Neyman, M Weinhous, M Ouzidane, Cleveland Clinic Foundation, Cleveland, OH

Purpose: To identify and resolve issues associated with transferring brain tumor patients, after placement of Leksell frame (LF) and the completion of MRI and CT scans for Gamma Knife (GK) radiosurgery, to linac-based stereotactic radiosurgery (SRS) with BrainLAB Novalis. **Method and Materials:** Three patients were studied. These patients could not technically be treated with GK radiosurgery given the technical limitations posed by frame placement or tumor location. CT and MRI scans were transferred to the BrainLAB treatment planning system (TPS), BrainSCAN. Treatment plans were then generated and evaluated. Systematic and potential issues were identified. Compatibility of the LF and the BrainLab system was evaluated. Imaging issues were investigated, and time restriction considerations to have the patient treated the same day were addressed. **Results:** The LF is compatible with the Novalis system using a special adapter. The MRI scans presented no issues. CT imaging may constitute an issue since the Leksell localizer box is shorter than the BrainLab box. Depending on the frame placement on the patient head, part of the anatomy may not be localized by BrainSCAN and cannot be used. While the GK TPS can extrapolate parts of the anatomy, BrainSCAN cannot. As a result, planning options are limited (novertex beams/arcs). In this case, a new CT scan with the LF and the BrainLAB localizer is required. Once imaging issues are resolved, a plan, quality assurance, evaluation and treatment can be completed the same day. **Conclusion:** Patients scheduled for GK radiosugery can be efficiently transferred to Novalis the same day of the procedure when tumor location or frame placement does not allow GK radiosurgery. The issues associated with the transfer are manageable and allow same day treatment with the Novalis system.

MONDAY, JULY 25

Imaging Continuing Education Course Room 618
CE: Breast Imaging Physics and Technology - I

MO-A-I-618-01
What the Medical Physicist Needs to Know and Do in Stereotactic Breast Biopsy
M High*, New York Medical College, Valhalla, NY

Both diagnostic and therapeutic applications of stereotactic mammography will be discussed. An overview of the American College of Radiology's Breast Biopsy Accreditation Program will be presented along with the recommendations of the associated ACR Stereotactic Breast Biopsy Quality Control Manual. Patient dose issues will be covered, including manufacturer recommendations for image receptor exposure levels, guidance for establishing a technique chart for 512 and 1024 images, and advice on identification of over- and under-exposed images, and the influence of kVp and mAs on dose and image quality. The application of stereotactic digital imaging to interstitial breast brachytherapy will be discussed.

Educational Objectives:
1. Review ACR Accreditation recommendations for QC testing of stereotactic breast biopsy units.
2. Become familiar with recognizing proper exposure levels and with setting up technique charts for appropriate image quality.
3. Become familiar with the application of stereotactic digital image to interstitial breast brachytherapy.

Imaging Continuing Education Course Room 617
CE: PET Physics and Technology - I

MO-A-I-617-01
PET Systems: Instrumentation and Data Acquisition
F Fahey*, Children's Hospital Boston, MA

Positron emission tomography or PET is now considered one of the most important clinical imaging modalities, particularly in the fields of oncology and neurology. In addition, the application of PET to cardiology is swiftly growing. This presentation will discuss the instrumentation as well as the data acquisition associated with state-of-the-art PET systems including PET-CT. This talk will review the basics of positron emission, annihilation coincidence detection and instrumentation design. It will review detector designs in state-of-the-art PET systems including the choice of detector materials. We will also describe both 2D and 3D PET data acquisition modes and the merits of each. We will discuss random coincidences, scatter and attenuation correction and current approaches being used to correct for these. For attenuation correction, calculated methods, measured methods using rotating rod sources as well as the use of CT will be discussed. At the end of this presentation, the participants will be able to:
1. list 3 detector materials routinely used in PET and at least one advantage or disadvantage of each,
2. describe the difference between 2D and 3D PET data acquisition.
3. discuss 3 current methods of attenuation correction used in PET and

MO-A-I-617-02
Image Reconstruction Strategies for Positron Emission Tomography
CS Levin*, Stanford University School of Medicine, Stanford, CA

This presentation gives an overview of image reconstruction strategies for PET. We will discuss two classes of PET reconstruction algorithms: analytical and iterative. Analytic approaches model the acquisition process as an analytic transform operator and treat both the measurement and reconstructed image as continuous functions. Analytical image reconstruction algorithms are based upon direct computation of the inverse transform formula. Iterative techniques consider the above functions as discrete and may incorporate statistical methods and accurate system models to determine the best solution. Iterative approaches may be more appropriate for photon count limited data and for PET systems with non-standard geometry. The analytic methods are typically more computationally efficient. We will focus only on those techniques implemented in the current state-of-the-art commercial PET systems.

Educational Objectives:
1. To understand the problem of image reconstruction in PET.
2. To become acquainted with analytic and iterative image reconstruction strategies for PET.

Imaging Continuing Education Course Room 609
CE: Digital Imaging Systems, Processing, Analysis and Display - I

MO-A-I-609-01
The Role of the Physicist in the Planning and Design of Digital Image Management Systems (PACS)
D Peck*, M Flynn*, Henry Ford Hospital System, Detroit, MI, Henry Ford Health System, Detroit, MI

A Digital Image Management System encompasses all information related to Diagnostic or Therapeutic images used in a clinical setting. This includes the order entry process, movement of the order information to a Modality, image acquisition and processing, movement of the image data to an archive, movement of the images and order data to Radiologist and Clinician viewing stations, and reporting the interpretation of the images. Note that a Digital Image Management System includes more than just image storage and viewing inferred by the title Picture Archive and Communication System (PACS). Therefore when a Physicist is asked to consult in planning a PACS they should be thinking about the workflow and data required to produce the final product, i.e. the Radiologist Report with associated images, and so they are actually consulting on the implementation of a Digital Image Management System. The areas that a Physicist should provide information to a site when planning such systems include:

1. Digital image acquisition/modality options for each study,
2. Modality integration and testing,
3. Bandwidth and storage requirements,
4. Radiologist and clinician softcopy viewing requirements,
5. Digital imaging Quality Assessment (QA) protocols

The needs in each of these areas relative to planning a Digital Image Management System will be reviewed with suggestions on further educational resources.

Educational Objectives:
1. Understand the workflow and Modality requirements in a Digital Image Management System.
2. Understand softcopy reading requirements compared to film based and considering the increasing image size and volume.
3. Consider the QA needs and methodologies with digital imaging systems.

Imaging Continuing Education Course Room 611
CE: Computed Tomography Physics and Technology - I

MO-A-I-611-01
Recent Advances in CT: MSCT and Highspeed Scanning
L Goldman*, Hartford Hospital, Hartford, CT

This lecture begins the CT refresher course series by reviewing fundamental concepts associated with CT image quality in axial and helical scanning, then focuses on principles of multislice CT. Some concepts associated with single-slice helical scanning are briefly reviewed as an

introduction to MSCT helical scanning concepts. The attendee will be familiarized with:
1. properties of the CT scan process affecting image quality, including sampling and scatter
2. traditional and new methods to improve sampling
3. principles of multislice CT scanning
4. MSCT detectors systems
5. reasons for potentially increased radiation doses in MSCT
6. Concepts associated with helical scanning and pitch in MSCT
7. Benefits of MSCT.
8. Current generations of MSCT systems
9. Improvements in gantry rotational speed and associated x-ray tube design

Therapy Continuing Education Course Room 6E
CE: QA for IMRT - I

MO-A-T-6E-01
Acceptance Testing and Systematic QA
B Mijnheer*, Netherlands Cancer Institute, Amsterdam, NL

Acceptance testing and systematic QA of planning and delivery of IMRT is different compared to corresponding procedures for other conformal RT techniques. The special hard- and software necessary for the planning and delivery of IMRT is rather complex while the vendors continuously offer improvements of their systems. With respect to the acceptance testing of IMRT delivery systems, high demands are made upon leaf position accuracy, linac performance for small MU delivery, the control system for leaf movement, and leaf speed stability. The treatment planning system requires a thorough insight in the factors determining the accuracy of the dose calculation such as the transmission and leakage through the leaves, the tongue-and-groove effect, the description of the penumbra and the dose outside the high-dose region. Furthermore the accuracy of the calculation of the dose in small fields and the effects of grid size on dose calculation and display should be known. Also the uncertainties in volume determinations and dose-volume histograms have to be assessed. A number of these tests have to be repeated if considerable modifications in hard- or software occur, for instance if a new sequencer is implemented. The routine clinical use of this complex treatment modality requires an efficient QA program, which should include (daily, weekly, monthly….) tests for the safe delivery of complex 3-D dose distributions. Specific tests for individual patient treatments should also be designed, which may include patient-specific measurements and/or an independent dose calculation. Programs for both acceptance testing and systematic QA should be adapted to the complexity of the IMRT techniques applied in a specific center, as well as to the resources available. Finally it can be noted that contrary to the situation in the US, IMRT in Europe was until recently only applied in a relatively small number of, mainly academic, institutions. The reason for this difference in widespread implementation was that in Europe IMRT was considered more as an experimental type of treatment technique requiring considerable resources. In recent years both the hard- and software became more mature, while also more experience with respect to QA of IMRT became available. As a consequence many more institutions, also smaller and busy clinics, started in Europe with IMRT, facing the problem of performing a comprehensive QA program in routine clinical practice. In various European countries (*e.g.*, Spain, Italy and the UK) documents for the guidance for the clinical implementation of IMRT are now in preparation. In these reports recommendations for both physical and clinical aspects of QA of IMRT are provided, while ESTRO is preparing a report dedicated to the verification of IMRT.

Educational Objectives:
1. To understand the special issues related to acceptance testing and systematic QA of planning and delivery of IMRT compared to those required for other conformal RT techniques.
2. To understand the various aspects of design and implementation of a program for acceptance testing and systematic QA of planning and delivery of IMRT.

Therapy Continuing Education Course Room 6C
CE: Managing Respiratory Motion

MO-A-T-6C-01
Managing Respiratory Motion in Radiation Oncology
P Keall[1], G Mageras[2], 1Virginia Commonwealth University, Richmond, VA, 2Memorial Sloan-Kettering Cancer Center, New York, NY

Intrafraction motion is an issue that is becoming increasingly important in the era of image-guided radiotherapy. Intrafraction motion can be caused by the respiratory, skeletal muscular, cardiac and gastrointestinal systems. Of these three systems, much research and development to date has been directed towards accounting for respiratory motion. Respiratory motion causes deleterious effects during the imaging, planning and delivery of radiation therapy. The management of respiratory motion in radiation oncology is the subject of this continuing education class which aims to advise medical physicists involved in the external beam radiation therapy of patients with thoracic and abdominal tumors that move due to respiratory motion. This session will describe the magnitude of respiratory motion, discuss radiotherapy-specific problems caused by respiratory motion, explain techniques that explicitly manage respiratory motion during radiotherapy and give recommendations in the application of these techniques for patient care, including quality assurance guidelines for these devices. The techniques to be described include respiratory gating, breath-hold techniques, forced shallow breathing and respiration-synchronized radiotherapy. This session intends to reflect the current state of the scientific understanding and technical methodology in imaging, treatment planning and radiation delivery for radiation oncology patients with tumors affected by respiratory motion. Issues requiring further study will also be raised.

The educational objectives of this course include:
1. Appreciate the effects of respiratory motion during the imaging, planning and delivery of radiotherapy.
2. Learn the various techniques that have been clinically applied to manage respiratory motion.
3. Understand the general and specific quality assurance requirements for different respiratory management techniques.
4. Describe the clinical process for managing patients with tumors affected by respiratory motion.

Therapy Continuing Education Course Room 6B
CE: Particles

MO-A-T-6B-01
Proton Beam Radiotherapy - The State of the Art
T Bortfeld*, H Paganetti*, H Kooy*, Massachusetts General Hospital, Boston, MA

The number of proton therapy centers has doubled every 10 years since the beginning of proton therapy in 1954. Today there are 22 proton centers in clinical operation worldwide. In the past 5 years proton and heavy charged particle therapy have received a particular boost in Japan and in Europe, but also in the USA, where there will soon be 5 clinical proton therapy centers. The increased interest in and application of proton therapy motivates this continuing education course. We assume that the audience has a basic understanding of the principles of proton radiotherapy but we will refresh memories by giving a brief review of the principles. The main purpose of the course is to give an update of relatively recent developments in proton beam radiotherapy.
The first part of the presentation will deal with the rationale of proton therapy. We will give a brief summary of the physical characteristics of proton-tissue interactions leading to the typical Bragg peak. We will review recent clinical studies describing the application of protons to new treatment sites, and compare protons with other treatment modalities. The radio-biological effectiveness (RBE) of proton therapy will be addressed next. In-vivo and in-vitro experiments to determine the RBE will be summarized. The proton RBE will also be compared to the RBE of carbon ions.
Next, we will discuss technological aspects proton therapy, starting with beam shaping devices in the “nozzle”. We will review passive double

scattering approaches such as the ones integrated in the NPTC and Loma Linda facilities. We will also review active pencil beam scanning techniques. The use of rotating gantries will be contrasted with fixed beamlines. We will then talk about cyclotrons vs. synchrotrons for proton acceleration.
The clinical workflow will be presented for the Northeast Proton Therapy Center (NPTC) in Boston as an example. In this context, we will specifically address important questions of patient setup and immobilization. Recent studies on economical aspects and cost per treatment will be discussed as well.
That protons beams stop in matter is their unique advantage (compared to conventional radiotherapy), but this also poses a challenge for proton treatment planning because the stopping position is somewhat uncertain. If possible, beam angles are selected that avoid stopping protons proximal to critical structures. In other cases "patch fields" are used. How protons are affected by organ motion and how the effects can be reduced will also be discussed. Finally, the potential of intensity-modulated proton therapy in making treatment plans more conformal and more robust will be presented.

Educational objectives
1. To be able to put the physical and clinical potential of proton therapy and its cost into perspective, especially in comparison with photon IMRT.
2. To name the main technical components of a proton therapy system and the design alternatives.
3. To name the characteristics and at least 2 main advantages of intensity-modulated proton therapy (IMPT)

Imaging Continuing Education Course Room 618
CE: Radiographic and Fluoroscopy Physics and Technology - I

MO-B-I-618-01
Recent Advances and State-Of-The-Art in Screen-Film Receptors and Film Processing
R Dickerson*, Kodak Research Laboratory, Rochester, NY

Purpose: This presentation discusses recent advances in film/screen radiography. These include a high-resolution high-contrast film/screen system for mammography, as well as a high-speed high-resolution film/screen system that provides improved image quality and opportunities for dose reduction, compared to an existing state-of-the-art, general purpose film/screen system. A description of the technical aspects and system design of these new systems is given. The new film features novel silver-halide microcrystals and is dual coated using a split E-layer coating format featuring gradient crossover control. Without sacrificing image quality, the new system can be exposed with existing intensifying screens and provides significant dose reductions. **Method and Materials:** This paper describes details of the system's design and performance. The film includes: 1) a dual-layer coating structure that provides high-speed and high-resolution imaging of chest and orthopedic imaging; 2) high sensitivity silver-halide microcrystals that provide high contrast and high resolution.
Modulation transfer function (MTF) measurements were used to describe the resolution of various film/screen combinations using this new radiographic film and they are compared to existing state-of-the-art film/screen systems. **Results:** Inverse square sensitometry and MTF measurements, as well as phantom and clinical radiographs using this new film/screen system, demonstrate several benefits. A significant dose reduction is possible without reducing image quality by using standard intensifying screens. In addition, significant image quality improvements are possible in orthopedic imaging using high-resolution extremity-intensifying screens at conventional radiation doses. **Conclusions:** We have designed, built, and implemented a novel film/screen system for general-purpose radiography that provides high-resolution images with a potential for dose reduction or MTF improvement. Initial clinical evaluation of the system demonstrates a 2X reduction in dose without sacrificing image quality. In addition, significant resolution improvements are possible at the conventional radiation doses.

MO-B-I-618-02
Overview of Digital Detector Technology
J Seibert*, UC Davis Medical Center, Sacramento, CA

There are various technologies available for the acquisition and display of digital radiographic images. A division has historically existed between "computed radiography" (CR) using photostimulable storage phosphors placed in a cassette holder with subsequent processing in a reader, and "direct radiography" (DR) using a detector with integrated electronics and direct readout and image display. In 2005, these distinctions are less obvious, as some storage phosphor (PSP) devices are automated with direct image display, and some direct flat-panel devices are used like a portable cassette. Generally speaking, rather than distinguishing digital detectors based on "CR versus DR", consideration of cassette versus cassetteless digital radiography is perhaps warranted as the technology advances. Besides the venerable cassette-based PSP detector and plate reader for large field of view imaging (35 × 43 cm), digital detector technologies now available include PSP line-scan systems in a cassetteless enclosure, optically coupled CCD-camera systems, fiber-optically coupled slot-scan CCD array detectors, indirect x-ray conversion scintillators and thin-film-transistor (TFT) photodiode arrays, and direct x-ray conversion semi-conductors layered on TFT detector arrays. Dedicated digital mammography detectors use similar technologies, with appropriate tuning for resolution and speed. Detective quantum efficiency measurements, equipment specifications, unique acquisition techniques (e.g., digital tomosynthesis and dual energy radiography), PACS/RIS integration and quality control issues are reviewed in the presentation.

Educational Objectives:
1. To describe digital radiography in general terms, and compare with screen-film detectors
2. To understand acquisition and information flow of digital radiography devices
3. To compare cassette and cassetteless operation in terms of resolution, dose efficiency and signal to noise ratio
4. To describe new data acquisition and image processing techniques
5. To consider PACS/RIS interface and design features for digital radiography

Imaging Continuing Education Course Room 617
CE: Magnetic Resonance Imaging Physics and Technology - I

MO-B-I-617-01
MR Accreditation Program Quality Control - Beyond Just the Scans and Measurements
C Keener*, Medical & Radiation Physics, Inc., San Antonio, TX,
University of Texas Health Science Center at San Antonio Department of Radiology

In recent years, the American College of Radiology (ACR) MR Accreditation Program (MRAP) has been adopted by more than 3000 facilities. Those sites agree to follow a quality control program set up and monitored by the medical physicist or MR scientist. They also agree to undergo initial and annual equipment evaluations by the medical physicist / MR scientist. There are several published documents, including the *ACR Phantom Test Guidance* and the *2001 ACR MR QC Manual*, which describe required phantom tests and performance criteria. While helpful in assisting sites with the submission of phantom images for accreditation, these documents allow great discretion to the medical physicist in setting up the QC program without providing similar guidance in troubleshooting problems for a wide variety of scanners.

A consulting medical physicist may see a wide variety of scanners, each for a short period of time, and needs to be able to provide the site with useful recommendations beyond the pass/fail status of the phantom tests. The physicist must gather this information from existing QC data and tests performed with the ACR and other readily-available phantoms. This lecture will describe additional information which can be gathered from those data to produce recommendations for improving MR image quality.

Educational Objectives:
1. Understand basic MR QC tests using the ACR and on-site phantoms and how the results of those tests can be combined and analyzed to troubleshoot problems.
2. Understand how QC test availability and results may vary depending on scanner manufacturer.
3. Understand how technologist QC data may be analyzed to troubleshoot QC problems.

Imaging Continuing Education Course Room 609
CE: Ultrasound Imaging Physics and Technology - I

MO-B-I-609-01
Ultrasound Probe Testing in Clinical Ultrasound QA Programs
E Boote[1], W Moore[2], (1) Univ Missouri, Columbia, MO, (2) Sonora Medical Systems, Longmont, CO

Purpose: Tissue mimicking phantoms have been the primary tools employed by physicists for Ultrasound equipment acceptance and quality control programs. Recently, a new device has become commercially available that allows physicists, clinical engineers and service personnel the ability to ascertain the level of performance for ultrasound probes, based upon interrogation of individual elements. This provides an additional tool for the physicist to use in evaluating the performance of ultrasound equipment.
Course Description: The first part of this course will discuss probe testing. Why probe testing is important and the ways in which defects in probes may affect ultrasound image quality. The device and how the results of the test can be interpreted will be presented. The second part of the course will present the use of this device as part of a clinical quality control program. This will include the use of phantoms and the device in an integrated fashion to provide valid acceptance testing and ongoing verification of system performance.

Educational Objectives:
1. The impact of transducer probe defects on image quality and Doppler ultrasound
2. How testing of individual probes elements can be performed
3. Interpretation of test results for probes
4. How to set up a program of Ultrasound QA/QC using phantoms and probe testing devices

Conflict of Interest: Wayne Moore is employed by Sonora Medical.

Imaging Continuing Education Course Room 611
CE: Radiation Safety and Risk Management - I

MO-B-I-611-01
The Role of the Medical Physicist in Preparing for Radiation Disasters
M Hartman*, University California Davis Medical Center, Sacramento, CA

Since 9/11, hospitals have seen the need to examine their emergency management plans to ensure that radiation disasters are adequately addressed. Hospitals need to be ready to deal with radiation casualties in addition to the possibility of many self-presenters who want to know whether they are contaminated. Hospitals need to be prepared to handle this situation in the first day or two after a disaster until state and federal agencies can mobilize. Medical physicists will play a vital role as responders and sources of accurate information for hospital staff, patients and the public.

Medical physicists will be asked to assist in the decision-making process if an event does occur. This course provides information on the handling of patients who are injured and may be irradiated and/or contaminated with radioactive material. The Center for Disease Control website has guidance on ways to handle self-presenters who may exceed the number of radiation casualties. The psychosocial considerations after a disaster will be discussed and its effects on staff, patients and the public. The course will also address issues to be anticipated for facility recovery after a disaster.

Educational Objectives:
1. To provide resources that are available for developing emergency plans that address radiation disasters and their unique policy considerations.
2. To show how to utilize radiation protection procedures and practices and know how to prepare the facility for radiological emergency medical response.
3. To provide a framework for handling self-presenters who will seek help from their local hospital to determine whether they are contaminated.
4. To understand the psychosocial considerations in responding to a radiological emergency.
5. To know what activities can occur during facility's recovery from a radiation disaster.

Therapy Continuing Education Course Room 6E
CE: Optimization for IMRT - I

MO-B-T-6E-01
Fundamental Issues in IMRT Treatment Planning
P Xia*, UC San Francisco, San Francisco, CA

Inverse planning in intensity-modulated radiotherapy (IMRT) drastically changes our thinking process in treatment planning because of using computer optimization. Unlike conventional forward planning, which highly depends on the geometric relationship between the tumor and the surrounding normal tissues, inverse planning critically depends on the specification of dose constraints to the target tumor and sensitive structures. For a particular inverse planning system, one has to have a good understanding of the inverse planning system and a good intuition about the relationship between the dose constraints and the resulting dose distributions. This review course session will focus on fundamental issues in IMRT treatment planning. We will try to answer the following questions: What are the basic components of commercial IMRT treatment planning systems, and how do they work? What is typical behavior of an IMRTP system? How can the user systematically search for a proper dose constraint for a specific disease site? How does the planner know when to quit trying to improve the plan? Lastly, to what extent and how can the typical problems with generated plans be ameliorated? Issues specific to head and neck and prostate IMRT treatment planning will be discussed.

Educational Objectives:
1. To understand the basic components of commercial IMRT treatment planning systems;
2. To obtain a good intuition about the relationship between the dose constraints and the resulting dose distributions;
3. To understand methods for developing class solutions for specific disease sites to streamline the planning process;
4. To understand special clinical issues related to IMRT treatment planning.

Research is supported by Siemens and Prowess.

Therapy Continuing Education Course Room 6C
CE: Imaging for Treatment Planning - I

MO-B-T-6C-01
Current Techniques for Image Registation and Data Fusion
Marc L Kessler*, University of Michigan Medical School, Ann Arbor, MI

Acquisition of anatomic and functional data from magnetic resonance imaging and nuclear medicine studies is becoming increasingly common for patient management in radiation therapy. These data can help improve tumor localization and normal tissue delineation for treatment planning and may provide information about treatment efficacy during or after a course of radiotherapy. Time series data from serial and 4D CT before and during the treatment course, including CT data acquired in the treatment room at the time of treatment, is also helping to estimate motion and shape changes of relevant anatomy. In order to fully realize the benefits of these data, the different imaging studies must be registered to a single coordinate system, typically that of the treatment planning CT. The geometric transformation that is used to register the different image data can range from simple

rotate-translate to account for differences in patient orientation to 3D or 4D deformation models to account for changes in internal anatomy during and over the course of therapy. Once mapped to a common coordinate system, data derived from the various studies such as anatomic outlines and computed dose can be integrated or fused to help construct a more complete and accurate representation of the patient.

A variety of interactive and automated techniques exist to carry out these steps. The general strategy for registration algorithms is to minimize a metric that measures the geometric mis-registration between pairs of datasets. Metrics can be derived from extracted geometric structures or from the image intensities directly. Once registered, computer graphics and algebraic techniques are used to combine data and create integrated displays.

This lecture will focus on the mechanics of registering and displaying data from different imaging studies using distinct modalities or a single modality over time. A taxonomy of the methods currently implemented in commercial and research treatment planning systems will be described. Methods for display and interaction with multimodality data will also be presented. The overall goal is to provide the basic knowledge required to understand what is happening "under-the-hood" of the different registration systems one might encounter in the clinic.

Educational Objectives:
1. Understand the basic mechanics of image registration and data fusion.
2. Understand the different registration algorithms used in commercial and research treatment planning systems.
3. Understand the different techniques used to combine, display and interact with multimodality image data.

Therapy Continuing Education Course Room 6B
CE: QA for TP Systems

MO-B-T-6B-01
Quality Assurance of Radiation Treatment Planning Systems: A Significant Challenge?
J Van Dyk*, London Regional Cancer Program, London Health Sciences Centre, London, ON, CA

During the last decade there has been a technological revolution in radiation oncology. Enhanced use of imaging combined with computer-controlled methods of dose delivery provides a capability of escalating tumor doses without increasing morbidity. A pivotal component of this modern technology is the computerized radiation treatment planning system (RTPS) which is used to develop optimal treatment techniques for individual patients. Modern RTPSs make increased use of patient images, possibly from various imaging modalities, enhanced 3-D displays, more sophisticated dose calculation algorithms, more complex treatment plan evaluation tools, combined with the generation of images which can be used for treatment verification. In addition, the implementation of intensity modulated radiation therapy (IMRT) has added a further complexity to the RTPS and this is combined with automated optimization software which is essential if IMRT is going to be used to its best advantage.

In recent years, various national and international organizations have developed reports that have made recommendations regarding the commissioning and quality assurance (QA) of RTPSs. In 1998, AAPM TG53 published guidelines for users and vendors on QA for radiation therapy planning. In 2000, the International Electrotechnical Commission (IEC) produced a report (IEC 62083) specifically on safety requirements for manufacturers of RTPSs. In 2004, both the International Atomic Energy Agency (IAEA) and the European Society of Therapeutic Radiation Oncology (ESTRO) published reports on commissioning and QA of RTPSs. Furthermore, the IAEA is presently in the process of developing a protocol for the acceptance testing of RTPSs. In 2005, the Netherlands Commission of Radiation Dosimetry also produced a report on QA of RTPSs. All of these reports indicate that a thorough commissioning of a modern 3-D RTPS has become a daunting task. This refresher course will look at some of these reports and review issues associated with the commissioning and quality assurance of a modern RTPS.

Educational Objectives:
1. To demonstrate the importance of QA of RTPSs by reviewing significant treatment errors associated with their use.
2. To review the major functionality of a modern RTPS.
3. To highlight and summarize various reports that have made recommendations regarding commissioning and QA of RTPSs.
4. To discuss accuracy requirements and criteria of acceptability of the modern RTPS.
5. To summarize acceptance testing procedures as proposed by the IAEA for a modern RTPS.
6. To provide an overview of commissioning a modern RTPS.
7. To provide an overview of the QA associated with a modern TPS.

Conflict of Interest: One of the QA tools described in this presentation was developed by the author and is marketed by Modus Medical Devices Inc.

Joint Imaging/Therapy Symposium Room 6E
President's Symposium
Einstein's Annus Mirabilis 1905 and Related Historical Goodies

MO-C-T-6E-04
Einstein 1905 and Beyond: The "Revolutionary" Paper, Plus Four, Plus Five
J Rigden*, Washington University, St. Louis, MO

In the short duration of six months, one week, and two days, Einstein, in 1905, wrote five papers that stand today at the bedrock of physics. Only one of these papers was, according to Einstein himself, revolutionary. This paper, on the nature of light, made him the father of quantum physics. In the other four papers, Einstein clearly eschewed trivialities as he demonstrated the reality of atoms and examined their dimensions (the reality of atoms was still debated in 1905), put the laws of thermodynamics on a new footing as he established the validity of the kinetic theory, enhanced the significance of the speed of light, and purged the basic concepts of space, time, mass, and energy of profound fallacies. But Einstein did not retire after 1905. He continued a career that, in sum, stands alone in the annals of physics.

MO-C-T-6E-05
Early History of Radiation Physics
P Almond*, UT M.D. Anderson Cancer Center, Houston, TX

In 1905, Einstein's annus mirabilis, Dr. Charles Lester Leonard began his presidential address to the American Roentgen Ray Society with, "A review of what has been accomplished in the decade since Roentgen's discovery is a fitting subject for the annual address in this decimal year…. It will form a base from which we can attempt to look into the future." I wonder if Dr. Leonard would recognize the future if he could be present at this meeting, a century later, and see what it became. In the decade between the discovery of X-rays by Roentgen in 1895 and Dr. Leonard's address much had happened in the world of radiation physics. Although there were new discoveries, especially that of radioactivity, the overall emphasis was upon the application of "radiation" to clinical problems without fully understanding the nature of the "radiation" or its interaction with matter, especially tissue. When Roentgen discovered X-rays in November 1895, the news spread rapidly through the continental Europe, Great Britain and the United States and many individuals began generating and using them. This was not surprising since the basic equipment was readily available, Crooks tubes, high voltage generators, induction coils, etc, especially in academic departments and the information in newspaper accounts of Roentgen's work was detailed enough to get started. Physicists were just as likely therefore to be involved as medical doctors. Unfortunately the above equipment, except for the Crook's tube, was also being used for what became called electro-therapeutics, the treatment of disease by electricity which on the whole was considered "quackery". In the fall-out between radiology and electro-therapeutics the physicists became caught in the middle. This created problems for medical physicist that would take half a century to start addressing. No such problem existed in Great Britain allowing medical physics to develop earlier there than in the United States.

Much of the development in the period 1985 to 1905 was in the area of X-rays, although radium had been discovered by the Curies in 1898 it was very expensive, in 1906 1 gram of radium cost $50,000, and demand far exceeded supply. However the clinical application of radium was clearly recognized and programs for its therapeutic use in the treatment of cancer had started at a number of institutions world- wide.
The major needs in 1905 were the requirement for the standardization of treatments, accurate measurement of radiation, reliable equipment and steady output, an understanding of the radiobiological effects of radiation, a basic understanding of the physics involved. In the next few years all of these questions would be extensively addressed.

Educational Objectives
1. To appreciate the status of clinical radiation physics in 1905.
2. To realize what was and what was not known about radiation physics in 1905
3. To appreciate the problems that still had to be addressed.

Professional Session Room 618
Professional Proferred Papers

MO-D-I-618-01
Estimating Medical Physicist FTE Using the 2003 Abt Survey and Procedure Volumes in Radiation Therapy
M Herman*[1], E Klein*[2], M Mills*[3], A Boyer*[4], (1)Mayo Clinic, Rochester, MN, (2)Mallinckrodt Inst of Radiology, Saint Louis, MO, (3)James Graham Brown Cancer Center, Louisville, KY, (4)Stanford Univ School of Med, Stanford, CA

Purpose: To estimate radiation therapy medical physicist FTE needs based on procedure numbers and published medical physicist work survey data.
Method and Materials: A spreadsheet was developed to combine procedure volumes requiring medical physicist effort with procedural time values extracted from the 2003 Abt survey and a previous survey on medical physics costs (Herman et. al. JACMP, 2003) and included:
Patient Procedures: Median procedural time efforts and annual volumes for CPT codes 77295, 77300-77370.
Commissioning and QA: Annualized time for commissioning and QA per major clinical system.
Education: Contact teaching time for medical residents, allied health and medical physics trainees with a preparation multiplier of 3 for didactic courses.
Research: A 10% factor was used, recognizing that development work varies considerably between practices.
Administration: A value between 10 and 15% was recommended by ACR.
FTE needs were summarized for a 3 machine practice (800 new patients), IMRT (250 pts per year), HDR(50), Radiosurgery(60), prostate implants(40) and TBI(30). Physician residents and one medical physics trainee are taught.
Results: A total of 9.4 FTE was calculated based on: Patient Procedures – 6.67, Commissioning and QA - 1.04
Education: - 0.11, Research: - 0.78, Administration: - 0.78. With shared duties, no specials and an efficient electronic record, for example, the FTE could be reduced to 7.3 FTE. **Conclusion:** A medical physics staffing complement of between 7.3 and 9.4 FTE is suggested by a model based on workloads from the 2003 Abt and procedure volumes in a clinic with 800 new patients. The range is due to the sharing of duties (with other professionals), efficiency and the absence of some procedures. The number of hours committed by the medical physicist for procedural effort versus non procedural effort must be evaluated/validated against one's specific practice to make proper use of data from the Abt.

MO-D-I-618-02
Survey of Quality Performance Status in Radiation Oncology Departments
K Schmanke*, T Schmanke, M Kitch, R Schuster, TMA Technology, Ltd., Grapevine, TX

Purpose: To survey quality assurance performance in both hospital-based and free-standing radiation oncology departments.
Method and Materials: Consisted of an online survey of 15 questions that was also mailed to 425 radiation oncology departments, covering topics ranging from peer review and issues, departmental processes and equipment, state reportable events, TG-40 recommendations and accredidation status. **Results:** We received 56 responses for a 13% response rate. Of these, 73% were from hospital-based and 27% from free-standing clinics. 80% reported conducting physician peer-review meetings, and discussed issues such as high risk/low volume procedures, unplanned treatment breaks (48%), mortality (41%), and reaccurences in adjacent and previously irradiated fields (31%). 93% reported knowing what is a state-reportable event, and 83% had conducted a root-cause analysis for a state-reportable event. 85% of the responders reported using Continues Quality Improvement (CQI) methods within the department and 50% cross-departmentally in an effort to improve the treatment processes. Tracking of quality indicators included patient satisfaction (95%), treatment misadministration (80%), physics check prior to 3rd treatment (73%), number of simulations and starts (48%), pateint wait time (36%), chart consistancy (30%), port film repeat rate (30%), machine overides (29%) and block re-cuts (7%). However, only 41% reported being accredidited by either the ACR or ACRO. In addition, 50% of respondants reported knowing the AAPM TG-40 guidelines, and only 32% of respondants tracked compliance with TG-40 recommendations.
Conclusion: The results represent a small sample size so must be interpreted cautiously. Overall responses indicate a lack of consistancy between departments in managing quality assurance issues. Responses also indicate a disregard for AAPM TG-40 reccomendations, and an overall lack of interest in accredidation.

MO-D-I-618-03
A Web-Based Lead Apparel Management System for Medical Enterprises
T Oshiro*, C Cagnon, B Rael, S Shah, J Urquidi, J Melendez, University of California Los Angeles Medical Center, Los Angeles, CA

Purpose: Accrediting bodies often require facilities to have a system for managing radiation protective apparel. In larger hospitals and medical enterprises, the standardization and monitoring of radiation protective apparel becomes increasingly difficult. The purpose of this work was to develop a web-based infrastructure for inventory control of radiation protective (lead) apparel across a large-scale hospital system. **Method and Materials:** A centralized database was developed and made accessible by a departmental website using Active Server Pages (ASP). Unique identifiers were assigned and entered into the database for the current apparel inventory. Quality control (QC) records – including lead patency checks were also integrated into the system. An automated email notification system was implemented for overdue QC tests. Web-based education modules were posted and an enterprise wide policy was formed to identify staff responsibilities and quality control methodology. **Results:** Responsible individuals were assigned to monitor local section inventory changes and ensure proper care of apparel. Quality checks, unique identification and centralized ordering of apparel were coordinated through the Medical Physics office. For the four major enterprise sections, (two hospitals – with inpatient and outpatient centers) over 1081 different pieces of lead apparel were uniquely identified, inventoried and inspected. The web-based system allowed staff and managers across the enterprise to access current inventory and latest quality control results for apparel in their section. Reminders of overdue checks are sent out monthly with no user interaction. **Conclusion:** The web-based information system is effective at dissemination of information throughout a medical enterprise. Centralized systems of inventory control and quality assurance testing reduce redundancy throughout departments. Assigning unique identifiers has the potential to reduce conflicts in inventory management and provides a system to return apparel that has been accidentally moved. Policy formation encourages this integration throughout the enterprise.

MO-D-I-618-04
A Cost-Effectiveness Model for New Radiation Oncology Technologies
M Mills*, W Spanos, R Esterhay, University of Louisville, Louisville, KY

Purpose: The additional equipment and personnel costs of supplying Intensity Modulated Radiation Therapy (IMRT) technology have caused many to question if the marginal gains in patient health-related quality of life are worth the additional cost. A novel IMRT technology, helical

tomotherapy, provides the opportunity to study cost and effectiveness for patients. **Method and Materials:** This methodological study proposes to evaluate the cost and effectiveness of treating conventional radiotherapy versus tomotherapy IMRT patients prospectively, among several institutions. The cost of treating patients varies between institutions, depending on personnel, equipment and overhead costs; however, the nature and quality of services provided are expected to be consistent. **Results:** The methodology study tracks cost information at a single institution, and simultaneously as the median from multiple institutions. Effectiveness measures include both standard quality adjusted life year instruments completed by patients and performance status measures completed by institutional personnel. In addition, disease specific effectiveness measures are accommodated in the study. Each participating institution uses the same effectiveness measures to track patients with similar disease. **Conclusion:** The resulting cost and effectiveness data is available to investigators at any point during the study, immediately upon the completion of a trial, or when statistical acceptability is achieved.

MO-D-I-618-05

Needs in Ionizing Radiation Measurements and Standards

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Purpose: The Council on Ionizing Radiation and Measurements and Standards (CIRMS) of which the American Association of Physicists in Medicine is an Organizational Member, has recently issued its triennial report identifying needs for standards in four primary areas: Radiation Protection, Medical Applications, Industrial Applications and Materials Effects, and Homeland Security. The report is used by the National Institute of Standards and Technology (NIST) and other government agencies to formulate and prioritize work in the development of appropriate standards. **Method and Materials:** Standards needs in the form of Measurement Program Descriptions (MPD) are formulated in a series of breakout sessions held during CIRMS annual meeting at NIST. Scientists from academia, government and industry collaborate in drafting the MPD's. **Results:** Twenty-one MPD's appear in the Fourth Needs Report with four relating to Medical Applications, one for Computational Methods, eight for Radiation Protection and three for Homeland Security. The remainder address the special situations encountered in industrial radiation processing. **Conclusion:** CIRMS represents an important vehicle by which NIST interfaces with the combined interests of the academic and industrial community. CIRMS involvement influenced the development of radiation standards pertinent to calibrating radiation measurement instruments used in mammography.

Imaging Scientific Session — Room 609

MRI and Nuclear Medicine

MO-D-I-609-01

Improved Target Localization in Low Field MR Using Local Weighted Mean(LWM) for Spatial Distortion Correction

S Samant*, J Xia, University of Florida, Gainesville, FL

Purpose: A methodology using local approximation method is presented for improving spatial distortion correction of Philips Panorama 0.23T MR-Simulator. The effect on accurate MR based segmentation is evaluated. **Method and Materials:** Standard T2 MR data was collected using the 0.23T MR-Simulator. For spatial distortion evaluation/ correction, a standard phantom with dimension of 14"*17"*1" containing a grid of MR markers at 2.5cm spacing was imaged. The spatial fidelity of the MR data was compared with the physical measurements of marker position using both the vendor supplied spatial distortion correction algorithm and our LWM algorithm, which employs local polynomial fitting and marker centroids serving as control points. The markers are automatically detected using a Gaussian kernel. CT-MR image registrations using normalized mutual information were applied to estimate the effect of spatial distortion on image registration. **Results:** Using LWM, the diameter of the imaging region with minimal spatial distortion (marker localization error < 1mm) increased to 300mm, in contrast to the Philips' correction method characterized by diameter=70mm. Visual inspection of clinical imaging data, including a case of craniopharyngioma, indicated such distortion is not readily discernible to the human eye. CT-MR registration results indicated that the normalized mutual information (NMI) increased about 5% after applying LWM to the MR data compared to using the vendor supplied algorithm. Shifts of up to 3mm were observed in segmentation involving off-axis target regions between LWM and vendor corrected MR data. **Conclusion:** LWM provides a significantly superior correction for spatial distortion associated with low field MR imaging compared to the vendor supplied correction. This improves target localization accuracy based on segmentation of off-axis structures, and increases NMI value of CT-MR registration. MR imaging with minimal spatial distortion allows the MR-simulator to be used to monitor tumor regression during radiotherapy.

MO-D-I-609-02

Performance Evaluation of Magnetic Field Homogeneity in MRI

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Purpose: Poor main (B_o) magnetic field homogeneity (MFH) leads to artifacts in MR images. The ACR MRI QC Manual mandates annual checks of MFH, suggesting tests using spectral line widths (FWHM) and phase-difference ($\Delta\phi$)maps. A new method for determining MFH is proposed and compared with standard methods using three different phantoms. **Method and Materials:** Small receiver bandwidth (BW) in the presence of poor MFH leads to geometric distortions because gradients are reduced to the level of the B_o inhomogeneities. The proposed bandwidth-difference (ΔBW) method compares the distortion for small and large BW acquisitions to determine the MFH. Data were acquired using a 3T system and FFE pulse sequence scanned twice with BW's of 50 Hz and 501Hz, respectively. MFH was measured from the shift of landmarks between the two BW acquisitions. Data were compared with data from the FWHM and $\Delta\phi$ methods. **Results:** Measured FWHM = 0.06 ppm@13.5cm DSV for the manufacturer's phantom, 0.27 ppm over the 19cm(diam) × 15cm(length) ACR phantom and 0.07ppm@27.9cm DSV in our spherical homogeneity phantom. The $\Delta\phi$ images showed pronounced areas of poor MFH near the corners of the ACR phantom, which were not evident in the other phantoms. The ΔBW method could not be used in phantoms without landmarks, but in the ACR phantom MFH was measured to be 0.43 ppm in the axial direction and 0.86 ppm in the saggital direction. In the spherical phantom ΔBW measurements show MFH=0.16 ppm@15.3 cm DSV to 0.32 ppm@18.83cm DSV. **Conclusion:** Spectral line width measurements of MFH on spherical phantoms can be useful however the acquired data are only for one DSV. The ΔBW method produces measurements of MFH at various DSV values that can be obtained from a single set of phantom images.

MO-D-I-609-03

Fast Dynamic MR Imaging for Tracking Lung Tumor Motion During the Respiratory Cycle

J Cai*, K Sheng, J Christopher, P Read, J Molloy, J Brookeman, University of Virginia, Charlottesville, VA

Purpose: To compare two MR sequences, HASTE and trueFISP, to track lung tumor motion and to assess tumor conspicuity and image artifacts. **Method and Materials:** A lung tumor motion phantom, three healthy volunteers and two lung tumor patients were examined using a clinical 1.5-T scanner (Sonata, Siemens, Germany) with the following parameters: trueFISP (TE/TR 1.5/204.2ms; FA/55°; FOV/300×300; matrix/128×128; slice-thickness/5mm), and HASTE (TE/TR 25/800ms; FA/160°; FOV/325×400; matrix/123×256; slice-thickness/5mm). No contrast agent or gating was used. Parenchyma signal intensity, lung regions and diaphragm displacement were measured in three healthy subjects. Tumor displacement, tumor SNR and tumor-to-parenchyma CNR were calculated in the two lung tumor patients. Tumor conspicuity and imaging artifacts were evaluated in all subjects by two radiation oncologists. **Results:** HASTE visualized better in peripheral vessels, but blurred tumor and central vessels. TrueFISP visualized better in non-peripheral vessels, but demonstrated ghost artifacts in the phase-encoding direction. Relative to CT, both sequences showed high SNR and CNR in patient #1 with the metastatic adenocarcinoma (HASTE 42.26/24.48; trueFISP 37.72/17.41; CT 42.04/29.98), but reduced SNR and CNR in patient #2 with the primary squamous cell carcinoma adenocarcinoma (HASTE 24.51/4.81; trueFISP 8.54/1.73; CT 36.67/26.84). **Conclusion:** HASTE and trueFISP can both

monitor lung tumor motion during free breathing. Tumor conspicuity and imaging artifacts depend upon the tumor type, size and location.

MO-D-I-609-04

In Vitro Stability of a Liposome-Based Multimodal Contrast Agent: A CT and MR Imaging Study

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Purpose: To investigate the stability of a liposome-based multimodal contrast agent for computed tomography (CT) and magnetic resonance (MR) imaging in the presence of various environmental conditions *in vitro* using both imaging and chemical analysis techniques. **Method and Materials:** Liposomes encapsulating iohexol and gadoteridol were dialyzed in an 8000 molecular weight cut-off dialysis bag against 250-fold excess of physiological buffer and fetal bovine serum (FBS) at 37°C. The liposome-based contrast agent was also irradiated to clinically relevant single doses ranging from 0.5 Gy to 32 Gy delivered at a rate of 3.9 Gy/min (6MV, photon beam, medical linear accelerator) at 37°C in physiological buffer and FBS. The same samples were imaged in a purpose-built multimodal phantom using CT (120 kV, 200 mA) and MR (1.5T, TR/TE = 450/9) before and after either dialysis or irradiation. The mean CT and MR signal differential was measured over circular regions of interest. Chemical detection of iohexol and gadoteridol concentrations was performed using high performance liquid chromatography and inductively coupled plasma atomic emission spectrometry respectively. **Results:** Partial release of the encapsulated agents occurred during dialysis due to differences in osmotic pressure and volume distribution (in the presence and absence of blood proteins). This small degree of agent leakage caused the MR signal to slightly increase and the CT signal to slightly decrease. In addition, the imaging properties of the system were found to remain unchanged when clinically relevant radiation doses were applied. **Conclusion:** The liposome-based multimodal contrast agent remained substantially stable under osmotic pressure and distribution volume changes, in the presence of blood proteins and clinically relevant radiation doses. This investigation showed the feasibility of employing this system for blood pool CT and MR imaging over the course of a radiation treatment.

MO-D-I-609-05

Uncertainties in Measuring Activity Concetrations of a Moving Phantom Aquired with Standard Clinical PET/CT Protocol

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Purpose: We have evaluated the magnitude of errors associated with measuring activities in moving objects in PET/CT images acquired using standard helical/clinical CT data. **Method and Materials:** In this study we used 2001 NEMA IEC Body phantom which has six fillable spheres with diameters of 37, 28, 22, 17, 13 and 10 mm. The target-to-background ^{18}FDG activity in a phantom was 8:1. A motorized platform moved the phantom with motion amplitude and period set to 2 cm and 5 s. All data was acquired using standard helical/clinical protocol: helical CT follow by PET emission scan. To determine uncertainties in activity measurements in stationary phantom we have acquired PET/CT scans of a phantom at 5 different positions. To evaluated the magnitude of errors in moving phantom we have reconstructed a PET image using emission data for the moving phantom and data for 30 different helical/clinical CT scans of the moving phantom acquired at random. **Results:** The uncertainties in measuring activities in the stationary phantom ranged from 9% for the largest sphere to 47% for the sphere with smallest diameter. The errors in measuring activity in the sphere in the moving phantom from 30 PET/CT image ranged from 10% to 33 % depending on the sphere's size. We have estimated the maximum possible observable error between the activity in stationary and moving phantom to be 21% for the largest and 75% for the smaller size sphere. **Conclusion:** The CT acquisition is on an order seconds and is fast enough that it will not acquire a motion-average CT scan. PET emission scan on the other had is a motion-average data. As a result, activity measured from PET/CT data acquired with standard helical/clinical protocol will vary depending on a start-time of the CT acquisition with respect to the phase of the motion cycle.

MO-D-I-609-06

Image Registration of Multi-Frame PET Data: A Simulation Study Comparing Individual Versus Collective Frame Registration Techniques

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Purpose: Image registration of a multi-frame data set in PET imaging has traditionally been performed by registering individual frames to a reference data set (IND method). In this abstract we propose, test and compare the results of a new approach that collectively register all image sets together (COL method) using a simulation study. **Method and Materials:** A lung lesion was simulated as a hot sphere oscillating in a warm background. The oscillation represented a patient breathing cycle. Images of the sphere at different phases of the breathing cycle were generated by first forward projecting the true image of the sphere into sinogram space, adding Poisson noise, and reconstructing the result using ML-EM. The reconstructed images were then registered using IND and COL methods. The same registration optimization was used for both methods. The registration quality of both methods was evaluated by calculating the mean square error (MSE) between the estimated and true displacement of the sphere at each phase of the breathing cycle following registration as well as by visual inspection. The results were also compared to an image of the sphere at a single phase and to that without motion. The effect of several simulation parameters on the registration quality were considered: 1) number of bins/cycle (10, 20, 40, 80); 2) Sphere to background ratio (2, 4, 8); and 3) number of breathing cycles (1, 2, 4, 8). **Results:** The MSE of COL is smaller than IND for the different simulation parameters. The improvement of COL over IND decreases as the sphere to background ratio increases, the number of bins decreases, and number of cycles increases. Visual inspection of COL registration showed better quality when compared to IND. **Conclusion:** COL gives better registration results by making use of all of the individual frames rather than registering one image set to another.

MO-D-I-609-07

Combined Scatter Subtraction and Digital Restoration of Ho-166 Images for Quantification

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Purpose: Ho-166-DOTMP used as targeted radiotherapy to the skeleton has shown great potential for treating multiple myeloma with improved therapeutic index. Potential kidney toxicity has suggested quantification of kidney activity in treatment planning. This has been limited by poor image quality, due to low abundance of imaging photons and relatively high septal penetration of 1.4-MeV photons. Scatter subtraction techniques have been limited because of poor counting statistics after subtraction. We explored the combination of digital restoration and scatter subtraction for Ho-166 image. **Method and Materials:** A medium-energy collimator was used as a compromise to maximize sensitivity and reduce septal penetration. One photon-window (81-keV) and 2 scatter-windows (lower: 57-73 keV, upper: 89-105 keV) were acquired on a Philips camera with a ¾inch crystal. Images were first subtracted with upper-scatters as energy spectrum from 1.4-MeV photons was flat. Digital restoration was used instead of further subtracting lower scatters. The line-spread function (LSF) was obtained from a subtracted image to determine the modulation transfer function (MTF) at 10-cm depth. Object power spectrum of the Wiener filter was estimated from image power spectrum of Tc-99m-DTPA and Ho-166-DOTMP of the same patient. **Results:** An upper-scatter subtraction-fraction of 1.0 was confirmed by assessing LSF in air. Subtraction of upper-scatter before Wiener filtering is necessary to remove various image artifacts due to 1.4-MeV photon penetration. The maximum response of the Wiener filter was 2 at 0.08 cycle/pixel and response was decreased to 0.1 at 0.25 cycle/pixel. Image degradation (FWTM) was reduced from 80-mm to 50-mm. Image counting statistics were improved as the total image counts were increased 30% after scatter subtraction and wiener filtering for kidney image 4-6 hour post injection.
Conclusion: Combined upper-scatter subtraction and digital restoration improves image quality, allowing quantification of kidney activity with adequate counting statistics to obtain reliable data.

MO-D-I-609-08

Validation of PET Hypoxia Tracers by Autoradiography and Fluorescent Microscopy

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Purpose: To develop a method for PET hypoxia tracer validation based on statistical analysis of the spatial correspondence between the intratumoral distributions of tracer uptake (assessed by digital autoradiography) and pimonidazole, an independent marker of hypoxia (assessed by immunofluorescent microscopy). The utility of the method was demonstrated by applying it to three PET hypoxia tracers, IAZGP, FMISO and Cu-ATSM. **Method and Materials:** Eight rats bearing R3327-AT tumors were divided into four groups of two animals each. Group#1 was injected with ^{18}F-FMISO and sacrificed 2hr later. Group#2 was injected with ^{124}I-IAZGP and sacrificed 3hr later. Groups#3 and #4 were injected with ^{64}Cu-ATSM and sacrificed, respectively, 24hr or 1hr later. Pimonidazole was administered to all animals 2hr before sacrifice. Tumors were excised, frozen and sectioned. Digital autoradiograms of the tracer distribution were obtained from selected sections and co-registered with images of pimonidazole-associated immunofluorescence derived from adjacent sections. The statistical analysis of association between PET tracer uptake and pimonidazole immunofluorescent staining intensity was then performed on a pixel-by-pixel basis. **Results:** For rats from group#1 correlation coefficients between pimonidazole-associated immunofluorescent staining intensity and ^{18}F-FMISO uptake were 0.84 and 0.75. For group#2 rats correlations between pimonidazole and ^{124}I-IAZGP were 0.85 and 0.77. For group#3 (^{64}Cu-ATSM administered 24hr prior to sacrifice), the correlations with pimonidazole were 0.61 and 0.64. However, for group#4 (^{64}Cu-ATSM administered 1hr prior to sacrifice), the correlation coefficients were -0.76 and -0.77, demonstrating that in this tumor model ^{64}Cu-ATSM uptake was not indicative of hypoxia at early times post injection. **Conclusion:** The proposed method enables evaluation of the degree of spatial correspondence between distributions of a PET tracer and alternative markers (either endogenous or exogenous) or tracers of the biological process under study. This method can be used for the *in-vivo* validation of any nuclear medicine tracer.

Imaging Scientific Session — Room 611

Computed Tomography

MO-D-I-611-01

Image Quality and Dose Characteristics of a New 85-Cm Multislice CT Scanner: A Comparison Study

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Purpose: The purpose of this study was to compare the image quality and dose performance of a new 85 cm 16-slice CT scanner with a standard 70 cm 16-slice CT scanner from the same company (Philips Medical Systems, Cleveland, Ohio), both used in a radiation oncology setting. **Method and Materials:** Image quality and dose performance tests were performed on a new 85 cm bore 16-slice CT scanner (Brilliance Big Bore) and a 70 cm bore 16-slice CT scanner (Brilliance 16 Power). The image quality tests were performed using the manufacturer-supplied phantoms provided with each scanner, as well as with a commercially available CT image performance phantom. The following tests were performed to evaluate image quality: slice width accuracy, CT number accuracy and linearity, CT number uniformity and noise, low contrast resolution, and high contrast (spatial) resolution. The computed tomography dose index (CTDI) measurements were performed using a standard CT dose phantom. The same head and body protocols were used for both scanners. To validate our results, images were sent to a third party company for independent analysis. **Results:** Slice width accuracy was within acceptable limits (±0.5 mm). Both scanners exhibited comparable CT number uniformity, accuracy, and linearity. The 85 cm bore scanner showed slightly higher noise. With equivalent mAs settings, large bore scanner low contrast resolution was comparable to the conventional scanner. High contrast resolution between the two scanners also demonstrated minimal differences. The head and body CTDI was 0.5-1.0 cGy higher with the 85 cm bore than for the standard 70 cm bore scanner. **Conclusion:** The overall image quality and dose performance of the new 85 cm bore 16-slice CT scanner are comparable to those of the standard 70 cm bore diagnostic quality multislice scanner. Therefore, the new big bore CT is appropriate for diagnostic radiology and radiotherapy applications.

MO-D-I-611-02

A Simple and Effective Method to Determine Clinical Significance of CT Ring Artifacts

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Purpose: To investigate the feasibility of using air scan to determine quantitatively whether CT ring artifacts are clinically significant. **Method and Materials:** Clinical contrast medium Optiray 320 was used to make CT artifact tools, which were attached to CT detectors at various locations. Preliminary scans of standard uniform phantoms were acquired on a 16-slice CT scanner with and without artifact tools. Images of an anthropomorphic phantom (ATOM, CIRS, Inc.) were acquired with the chest pulmonary embolus protocol to determine whether the rings are clinically significant. Air scans were acquired with the same artifact tools in place using a clinical as well as a QC protocol. Standard deviation values of ROI placed in images of uniform phantoms and air scans were recorded. The air scan data associated with the rings that are least visible in the anthropomorphic phantoms were used to investigate whether a threshold exists which indicates if rings are clinically significant. **Results:** Sensitivity of this method varies slightly with image thickness, mAs, scan mode, and ROI size. Evaluation of QC air scans showed good separation of the standard deviation values between "blank" air scans and those with artifacts for different ring diameters. Different threshold values were found based on size of ROI used to measure standard deviation, and it is necessary to use at least two different ROI sizes for either small or large ring artifacts. **Conclusion:** While air scans are overly sensitive for the visual detection of ring artifacts in CT images, they may be useful in establishing quantitative criteria for determining whether the rings present are clinically significant. With stack mode viewing, a quick and simple evaluation may be feasible for multidetector row CT scanners of large number of data channels for those institutions without the means to develop automated off-line analysis.

MO-D-I-611-03

A New Fan-Beam Data Consistency Condition to Estimate Erroneous Or Missing Projection Data

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Purpose: During diagnostic x-ray CT imaging procedures or image guided radiotherapy, some projection data may be missing due to malfunctioning detectors or limited field of view (LFOV) which is not big enough to cover the entire object. We present and validate a novel fan-beam data consistency condition (FDCC) to estimate missed or erroneous data due to the conditions given above. **Method and Materials:** A local Fourier transform of fan-beam projection data is introduced and the relationship with the Fourier transform of image function is established. Using the property of causality, a new FDCC is derived. The new FDCC provides an explicit estimation of any given missing projection data by filtering all other available fan-beam projections. This algorithm can be used to reduce the severity of artifacts when there are erroneous projection values present in the measured sinogram. The reconstructed image quality is significantly improved after correction compared to the image quality achieved by directly reconstructing with corrupted projection data. **Results:** Numerical simulations have been conducted using this FDCC in the case that some detectors are out of order and constantly report a zero value. Two images of Shepp-Logan phantom are reconstructed using the standard filtered backprojection (FBP) reconstruction algorithm. One image is reconstructed with the original corrupted projection data and the other one is reconstructed with the projection data corrected by FDCC. Details in the phantom not visible in the original reconstruction are recovered and ring artifacts are significantly reduced using this algorithm. **Conclusion:** This new FDCC was validated and has been proven to be a very powerful tool in correcting ring artifacts caused by corrupted projection data. Although the simulation was conducted for the malfunctioning detector case, this algorithm can be similarly applied to the LFOV case.

MO-D-I-611-04

Region-Of-Interest (ROI) Computed Tomography: Combining Dual Resolution XRII Images

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Purpose: High-resolution computed tomographic systems can require large radiation dose for full-field-of-view (FFOV) reconstructions. We have developed a method for obtaining data inside an ROI at high-dose and high-resolution and combining it with low-dose, low-resolution data outside the ROI. The combined image is reconstructed to obtain improved image quality both inside and outside the ROI but at reduced integral dose. **Method and Materials:** Projection images of a head phantom were obtained using the 5" and 12" modes of an x-ray image intensifier. The 5" mode effectively defined an ROI and the 12" mode encompassed the whole object (i.e., FFOV), but at 1/4 the dose of the 5" mode. The 5" and 12" projection images were aligned and combined. Since the data outside the ROI was obtained at a lower dose, the intensity inside and outside the ROI in the combined image was equalized prior to backprojection. The mapping function was determined, using the pixels lying just inside and outside the ROI. A second approach was simulated by assigning the average pixel value in the ROI to all pixels outside the ROI. Both cases were reconstructed using a Feldkamp cone-beam algorithm. **Results:** For both cases, we obtained reconstruction comparable to FFOV reconstruction inside the ROI. However, the combined image produced a reconstructed image comparable to the FFOV reconstruction outside the ROI as well. Moreover, the resolution of the region inside the ROI in the reconstructed image was determined by the 5" mode as opposed to the 12" mode. **Conclusion:** ROI CT using two sets of data provides a way to reconstruct an ROI with greatly reduced integral dose and artifacts and yet improved spatial resolution.

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MO-D-I-611-05

Characterization of Motion Artifacts On CT-Reconstructed Images Using ROI-Based Features

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Purpose: The purpose of this abstract is to demonstrate the potential of characterizing motion artifacts in CT-reconstructed images using ROI-based features. **Method and Materials:** Two model systems undergoing periodic motion were included in this study. The first consisted of elliptical objects undergoing periodic motion at frequencies similar to patient heart rates. The second consisted of 4D attenuation maps of a beating heart with coronary plaques in the LAD and LCX generated at pre-specified spatial resolutions with the NCAT 2.0 program developed by *Segars et al*. Sinograms were acquired and images were reconstructed at successive phase intervals using parameters similar to those used in clinical cardiac MDCT acquisitions. Images reconstructed at successive phases were compared using three similarity metrics: the mean absolute difference (MAD) and correlation metrics (CORR) described in *Manzke et al* and a root mean-square (RMS) metric. These metrics were applied over entire images and evenly-sized regions of interest (ROIs) within the images. These metrics were plotted over successive reconstruction intervals. Spatial maps of these metrics displayed over evenly-spaced ROIs at particular reconstruction intervals also were created. All simulations were performed using IDL 6.0 (Interactive Data Language, Research Systems Inc.). **Results:** Applying similarity metrics to evenly spaced ROIs within reconstructed images were effective in depicting regions around the moving ellipse that were more susceptible to motion artifacts. When applied to ROIs in an NCAT image reconstructed at a starting phase of 80% RR, the MAD and RMS values for the LCX ROI were 3.3 and 2.9 times greater than the corresponding values for the LAD ROI. The LAD plaque was much more visually apparent than the LCX plaque on the image. **Conclusion:** ROI-based features have the potential for characterizing the spatial-distribution of motion artifacts.

MO-D-I-611-06

Reduction of Motion Blurring Artifact Using Respiratory Gated CT: A Quantitative Evaluation

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Purpose: To develop a technique for reducing respiratory motion blurring artifacts using respiratory-gated CT, and to quantitatively evaluate the artifact reduction. **Method and Materials:** Similar to electrocardiogram (ECG) gated imaging for the heart, a synthetic sinogram was built from multiple scans intercepting a respiration gated window. A gated CT image was then reconstructed by the filtered back-projection algorithm. CT images of wedge phantoms moving at different speeds, and 13 patients were taken with synchronized respiratory motion measurement. The scanner was operated in ciné mode with 100 and 15 scans (0.5 s rotation) acquired consecutively at each couch position for phantoms and patients, respectively. Two error functions were fit to the CT profile across the air-phantom or lung-diaphragm boundaries for a quantitative evaluation of the blurring artifact. **Results:** The blurring artifact was reduced significantly at the air-phantom boundaries in the gated image. The gated image of phantoms with a motion of 20 mm/s showed similar blurring artifacts as the non-gated image of phantoms with a motion of 10 mm/s. The blurring artifact had a linear relationship with both the speed and the tangent of the wedge angles. The blurring artifacts were also reduced at the lung-diaphragm boundaries for patients. Centers of the two fitted error functions provided a reliable measure of large blurring, and were found equivalent to 25% and 75% locations of the CT profile. **Conclusion:** The respiratory gated CT imaging reduced the blurring artifacts for both moving phantoms and patients. This technique may be applied for other tomographic imaging modalities that require long imaging times with significant motion blurring artifacts, such as PET.

Keywords: Motion artifact, CT, Respiratory motion, Sinogram

MO-D-I-611-07

The Influence of Bowtie Filters On X-Ray CT Signals

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Purpose: Bowtie filters are commonly employed in CT scanners to minimize radiation dose by reducing intensity variations across detector elements in the presence of patient anatomy. This filtration modifies a number of x-ray beam properties (effective energy, flux, first and second order statistics), making them non-uniform across the fan beam field of view. Because these phenomena are not usually included in analysis of CT performance, this presentation will quantify the influence of bowtie filters on sinogram measurements and demonstrate their effect in reconstructed images. **Method and Materials:** A model developed for energy integrating x-ray detectors, extended to bowtie filters, was used to compute signal means, variances, and beam quality for a realistic scanner configuration. Experimental measurements were acquired with cylinder phantoms located off-isocenter, allowing objects to sample different portions of the fan beam. Using measured bowtie filter profiles and clinical CT patient scan data, simulated dose reduction images were generated to show visual effects. This approach was used to study a novel dose reduction method, region of interest (ROI) scanning, wherein full intensity is applied only to a local volume of interest while surrounding tissue receives a significantly lower dose. **Results:** The dominant effect of the bowtie filter is to increase noise in the periphery of the image field. A variation of effective energy results in a small amount of nonlinearity, which can be effectively corrected through calibration. Differences in second order statistics are at the threshold of observer detection. ROI scanning achieves very good local image quality while reducing dose in surrounding tissue. **Conclusion:** When bowtie filters are properly implemented, they provide reduction of patient exposure with minimal image degradation. The impact of bowtie filters on CT signals is significant and must be accounted for in accurate modeling of the scanning process.

MO-D-I-611-08

Statistical Reconstruction of X-Ray CT Images From Energy-Integrated Signals: A Simulation Study

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Purpose: Statistical reconstruction (SR) algorithms have the potential to significantly reduce X-ray CT image artifacts due to a more realistic model of the detector signal acquisition process. Most SR algorithms assume that the CT detectors are photon-counting devices and generate Poisson-distributed signals. However, actual CT detectors integrate energy and exhibit compound Poisson distributed signal statistics. The goal of this study is to assess the impact on image quality of the resultant mismatch between the detector and signal statistics models assumed by the sinogram and the reconstruction algorithm. **Method and Materials:** A 2D CT projection simulator software was created to generate synthetic polyenergetic transmission data assuming i) photon-count signals with simple Poisson distribution and ii) energy-weighted compound Poisson distributed signals. An Alternating Minimization (AM) algorithm was used to reconstruct images from the data models i) and ii) for a typical abdominal scan protocol and for incident particle fluence levels ranging from 10^5 to 1.6×10^6 photons/detector. The phantoms simulated included normal soft tissue, bone, and metal inserts. The images reconstructed from data models i) and ii) were compared by visual inspection and quantitative image-quality measures. **Results:** Substantial streaking artifacts appear in images formed from energy-integrated data when the AM algorithm assumes a particle-fluence spectrum $\bar{\Phi}_0(E)$. Once AM's spectrum is replaced by the energy-fluence spectrum $E\cdot\bar{\Phi}_0(E)$, AM correctly predicts the data means and eliminates the artifacts. With the energy-weighted spectrum, the reconstructed image quality from data models i) and ii) does not differ significantly even when SNR is very low. **Conclusion:** Mismatch between the actual and assumed CT detector signal statistics does not significantly degrade image quality once systematic data means mismatches are corrected. Within the context of statistical image reconstruction, there appears to be no benefit to develop more complex statistical reconstruction algorithms based upon energy-integrating detector signal statistics models.

MO-D-I-611-09

Effect of the Photon Counting CT Acquisition On Beam Hardening Artifacts

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Purpose: Low noise performance of the photon counting x-ray image acquisition applies also to CT when CT projections are acquired using a photon counting detector. However, the photon counting detector assigns a different weighting factor to the photons as compared to charge integrating, and the photon energy spectrum in the output of the detector is represented differently. This results in different magnitudes of the beam hardening artifacts in CT images acquired with photon counting and charge integrating detectors. Purpose of this work was to evaluate the effect of the photon counting on beam hardening artifacts in CT. **Method and Materials:** CT images of the head and breast equivalent phantoms including high and low contrast inserts were simulated at 120 kVp and 90 kVp x-ray tube voltages. Photon counting, charge integrating and energy weighting detectors with photon energy weighting factors of 1, E and E^{-3}, respectively, were considered. Magnitudes of the beam hardening artifacts were quantified and compared for these detectors. **Results:** Photon counting detector resulted in 4.5% increase of the magnitude of beam hardening artifacts from bone inserts as compared to charge integrating. The most optimal weighting of E^{-3}, which provides the highest SNR, however, resulted in 18% increase in beam hardening artifacts from bone inserts. The magnitude of the "cupping" artifacts was higher by 2% and 5% for photon counting and energy weighting detectors, respectively, as compared to charge integrating. Only the photon counting provided accurate representation of the beam hardening effect due to its flat energy weighting. The charge integrating and energy weighting distorted the beam hardening effect because of energy dependent weighting factors. **Conclusion:** It is concluded that the low noise capabilities of the photon counting CT will not be compromised by the slight increase on appearance of the beam hardening artifacts.

Imaging Symposium Room 6B

Flat-Panel Detectors: Advanced Applications

MO-D-I-6B-01

Introduction

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MO-D-I-6B-02

Active Matrix, Flat-Panel Imagers: From Rigid and Simple to Flexible and Smart

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Almost two decades of intensive research and development have transformed the concept of capturing x-ray images with large area, solid-state devices based on active matrix addressing into a wide range of highly useful technologies. These digital technologies are based on the use of two-dimensional matrices of thin-film transistors utilizing amorphous silicon semiconductors, along with scintillator- or photoconductor-based x-ray converters. The numerous advantages of this general approach have led to the widespread introduction of active matrix, flat-panel imagers for projection and cone-beam tomographic applications in mammography, radiography, fluoroscopy, radiotherapy and other medical and industrial applications. However, it has become apparent that current devices suffer from a number of intrinsic limitations that affect their cost, performance, robustness, and form factor. Intriguingly, technologies emerging from on-going advances in displays offer the potential of enabling the creation of fundamentally different forms of active matrix x-ray imagers. These imagers would incorporate such innovations as flexible, plastic substrates or sophisticated in-pixel circuitry. In this presentation, an overview of possible directions for active matrix imager development will be presented, along with a description of the underlying advances in semiconductors and processing techniques that will drive these changes. In addition, the potential impact of such radically different forms of imagers upon performance, use and availability will be discussed.

Educational Objectives:

1. Review strengths and limitations of present-day active matrix x-ray imagers.
2. Describe semiconductor- and processing-based enhancements that could circumvent these limitations
3. Summarize likely effects of the application of such innovations to active matrix imager design

MO-D-I-6B-03

Cone-Beam CT with Flat-Panel Detectors: Applications in Diagnostic and Image-Guided Procedures

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Flat-panel detectors featuring real-time readout, distortionless image capture, and high imaging performance at low dose offer a breakthrough technology for fully 3D x-ray imaging. Used in conjunction with techniques for 3D reconstruction, flat-panel cone-beam computed tomography provides soft-tissue imaging capability in combination with nearly isotropic, sub-millimeter 3D spatial resolution. Depending on the application and implementation, the volumetric field of view achieved in a single rotation about the patient is large (e.g., 40 x 40 x 25 cm3), and the imaging dose is low (e.g., lower than that of a diagnostic CT scan). Applications of flat-panel cone-beam CT represent a broad spectrum of medical imaging research. In breast imaging, dedicated cone-beam CT scanners could dramatically increase the sensitivity and specificity of subtle lesion detection. In small animal imaging, systems offering high-resolution, high-speed 3D imaging will likely form an important technology for imaging therapeutic response. In image-guided radiation therapy, flat-panel cone-beam CT is being used to guide precise radiation delivery based on the position of soft-tissue targets at the time of therapy. And in image-guided surgery, systems are under development for multi-mode fluoroscopic / cone-beam CT guidance in a broad range of procedures, including head-and-neck surgery, orthopedic and spinal surgery, and interventional radiology. The basic process of 3D image formation, the physical factors that challenge imaging performance, the scope of

applications in diagnostic and image-guided procedures, and important areas for future research are discussed.

Educational Objectives:
1. Understand the means by which volumetric cone-beam CT images are reconstructed from multiple projections acquired using a flat-panel detector.
2. Understand the physical factors (e.g., x-ray scatter) that limit image quality in cone-beam CT.
3. Discuss the latest applications of flat-panel cone-beam CT in medical imaging, including:
    a. Diagnostic imaging
    b. Small animal imaging
    c. Image-guided radiation therapy
    d. Image-guided surgery
4. Discuss the near and long-term areas of research in fully 3D digital x-ray imaging.

MO-D-I-6B-04

Matrix Inversion Tomosynthesis (MITS) Imaging of the Chest

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Tomosynthesis is a method for reconstructing 3-dimensional (3-D) image data from a series of x-ray projection radiographs, acquired with limited motion of the x-ray source (typically no more than 40 degrees). Digital tomosynthesis (DTS) is implemented with a flat-panel digital detector and can be integrated into standard digital chest radiography or mammography systems, providing a flexible platform for the acquisition of 3-D image data in the clinical environment. DTS can be performed with short acquisition times (single breath-hold duration), and requires lower dose and will likely be less expensive than traditional CT. Resolution in DTS images is high in the two dimensions displayed by a single reconstructed plane, but is reduced in the third dimension (plane-to-plane) by the limited scan angle. Conventional tomosynthesis reconstructs 3-D planes by simply shifting and summing projection images to bring a user-specified depth into focus. Unfortunately, planes reconstructed in this manner contain substantial low-frequency tomographic blur from distant anatomy, which reduces the visibility of in-plane structure. More sophisticated reconstruction methods include filtered-backprojection, direct inverse solutions, and iterative inverse algorithms which allow the user to impose constraints upon the inverse solution. Matrix inversion tomosynthesis (MITS) is a direct inverse solution which uses the known image acquisition geometry to model a set of conventional tomosynthesis planes in terms of true in-plane structure and out-of-plane tomographic blur. In-plane structure is separated from residual blur by solving systems of linear algebraic equations in the Fourier domain. Resulting MITS reconstructions exhibit enhanced visibility of in-plane anatomy compared with conventional tomosynthesis planes. MITS imaging of the chest is likely to improve the detection of lung nodules by resolving anatomy which would otherwise overlap in radiographs. A MITS pilot study was performed with 20 human volunteers who were known to have subtle pulmonary lung nodules, as determined by CT. MITS projection images were collected using a commercial x-ray tube and stationary flat-panel detector, equipped with prototype rapid-readout electronics. Angulation of the x-ray source was controlled with prototype motion hardware constructed in our laboratory. Total tomosynthesis exposures ranged from 1x to 2x the radiation exposure that would have been necessary to acquire a 250-speed film/screen lateral radiograph. All projection data was acquired during a single breath-hold (roughly 11 seconds). Preliminary human observer results indicate that MITS improved the sensitivity of retrospective lung nodule detection by 50% compared with standard radiography in the pilot study. This work was supported in part by grants from the National Institutes of Health (RO1 CA80490) and G. E. Medical Systems.

Educational Objectives:
1. To gain a general understanding of tomosynthesis and its relation to both radiography and computed tomography.
2. To understand the benefits and limitations of tomosynthesis.
3. To view sample human chest tomosynthesis data for illustration of key concepts.

MO-D-I-6B-05

Methods and Applications of Digital Breast Tomosynthesis

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Digital breast tomosynthesis (DBT) has been investigated to solve the problem of tissue-overlap in breast imaging. Our current DBT prototype acquires 11 projections by rotating the x-ray tube over a 50˚ arc (-25º to 25º, 5ºangular steps) using an amorphous silicon (CsI:Tl) flat-panel detector (1800×2304 pixels, 0.1 mm pixel size). The breast and the detector are stationary during the 7-second acquisition. A Rh/Rh target/filter combination is used and the total average glandular dose is less than that of conventional two-view mammography. An iterative maximum likelihood algorithm is used for reconstruction of the breast volume. This algorithm has been parallelized and implemented on both computer cluster and dedicated reconstruction board for fast computing speed. A DBT reconstruction consists of multiple slices parallel to the detector plane. The in-plane (XY) spatial resolution of the tomosynthesis reconstruction is determined by the spatial resolution of the detector. The in-plane (XY) spatial resolution is determined by detector resolution while the resolution in the third dimension (Z) is limited due to the limited angular range. Currently, a DBT reconstruction has 0.1 mm in-plane pixel size and 1 mm slice thickness. The in-plane quality and Z-resolution of DBT are characterized using a mammography phantom. More than 400 patients have participated the DBT clinical study. It is shown in both phantom and patient images that the superimposed tissues are separated by DBT. Clinical studies show that findings are better characterized in DBT since the breast tissue structure noise has been removed. DBT is able to find cancers that are obscured by overlapping tissues in conventional mammography. DBT also reduces false-positive callbacks that are caused by "fake tumors" (superimposed normal tissues). Initial investigations on DBT-based clinical applications include DBT-aided biopsy, DBT with contrast agent and CAD. A second-generation DBT system is being installed. It acquires 15 projections over a slightly larger angular range using a new a-Si detector with less noise. A 3000-patient study will be performed using this new system. Performance of the new system and the clinical study will be reported at the time of the meeting.

Educational Objectives:
1. To understand the principles of digital breast tomosynthesis
2. To understand image processing, reconstruction, visualization and quality evaluation methods for DBT
3. To understand the status of the clinical study on DBT and the potential clinical applications

Joint Imaging/Therapy Symposium Room 6C

Memorial Session in Honor of John S. Laughlin: Imaging for Target Definition

MO-D-J-6C-01

Memorial

J St. Germain*, Mem Sloan-Kettering Cancer Ctr, New York, NY

MO-D-J-6C-02

Breast Cancer Extent Determination by Imaging and Tumor Sections

M Yaffe*, G Clarke, Univ Toronto, Toronto, ON, CA

Although disease is frequently detected through imaging, it is the histological evaluation that provides the definitive diagnosis. Histological information also allows characterization of the disease and this information may influence therapeutic decisions. Frequently the extent of disease is underestimated on imaging and the histological examination provides information regarding multifocal disease as well as the size of the surgical disease-free margins surrounding the lesion. The probability of disease-free survival is related to margin size. Current histological methods used in the management of breast cancer suffer from three major limitations. These are: 1) the loss of information on the *in-vivo* conformation of tissue upon its removal from the breast, 2) difficulty in relating two-dimensional information seen on the small slides to the distribution of disease within a volume of tissue and 3) the undersampling of the tissue evaluated in the exam. We have begun a program to address these limitations through an approach that involves stabilization of the resected tissue in a gel,

production of whole mount tissue sections, digital microscopy and efficient, high resolution 2-dimensional and 3-dimensional computer display of the images. To accomplish these goals it was necessary to develop new techniques for tissue processing and for image acquisition. This included the identification of a gel that would provide the required mechanical properties for maintaining tissue conformation while being compatible with the chemicals used for processing. Special tissue slicing methods were also implemented to allow reliable production of large tissue sections, a particular challenge for breast tissue. A modified regimen of processing yielded artifact-free serial sections. A modular multi-port microscope was modified to accommodate the large (12.5 cm x 17.5 cm) glass slides and provide computer-controlled indexing of the slide across the microscope's field of view to acquire the image digitally as a large set of sub-images or "tiles". Software was developed for automated focussing and registration of the mosaic of thousands of tiles to build the complete image. A database was used to keep track of the tiles and their registration. Images were displayed on a 9.2 Mpixel color monitor and a hierarchical display system facilitated the compromises associated with viewing the enormous data set (> 4 Gbytes per section) at different spatial resolutions and field sizes. The system is currently being used to address a number of questions related to breast cancer therapy planning as well as being applied to other tissue types.

MO-D-J-6C-03

Pathology-Based Validation of Head and Neck Imaging: How Far Are We From the Truth?

V Gregoire*, UCL St-Luc University Hospital, Brussels, BE

The use of 3D conformal radiotherapy (3DCRT) and IMRT in head and neck squamous cell carcinoma (HNSCC) which permits exquisite dose distribution to volumes of almost any shape, has critically raised the issue of accurate delineation of the macroscopic tumor volume (GTV) and its microscopic extension (CTV). For various physical and logistics reasons, CT scan has been (and is still) typically the main modality used for treatment planning purpose. Image guided therapy with MR and FDG-PET is however under evaluation.
The combination of these imaging modalities has in turn raised the issue of their specificity and sensitivity with regards to the delineation of the GTV. In this framework, our group performed a comprehensive comparison of the tumor extension assessed by CT, MR and FDG-PET to the surgical specimen in a series of locally advanced laryngeal squamous cell carcinomas scheduled for total laryngectomy. A unique methodology was developed to allow 3D-registration of CT, MR and PET images performed before surgery to the macroscopic specimen. GTVs could then be delineated on the various images and on the pathologic specimens, and compared quantitatively and qualitatively. It was shown that all imaging modalities significantly overestimated the tumor volume compared to the macroscopic specimen, illustrating their lack of specificity for assessing tumor extension. The GTV delineated from the FDG-PET images was however the closer to the macroscopic specimen. Another interesting finding was that all imaging modalities underestimated a small fraction (around 10%) of the tumor volume corresponding to superficial extension, illustrating their limitation in spatial resolution.
This study has clearly demonstrated the limitation of the imaging modalities used for 3DCRT and IMRT of HNSCC, and emphasized on the usefulness of the CTV not only to take into account the microscopic tumor extension, but also to take into account the lack of sensitivity of the imaging modalities used for treatment planning.

MO-D-J-6C-04

Tumor Hypoxia Imaging

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Purpose: To develop the methodology for measuring tumor hypoxia and defining the hypoxic volume **Method and Materials:** PET imaging with hypoxia-affined radiolabeled tracers is promising as a method to define hypoxic volume in tumors, although validation of the images are still lacking. We evaluate PET imaging with several tracers in rodent tumor models and compare them to direct pO2 probe measurement for validation. In addition, using hypoxia-inducible reporter gene the expression of which can be imaged with PET, we attempt to directly link the molecular event of biological hypoxia to non-invasive imaging. Extension of the study to the clinic is being planned. **Results:** Microscopic distribution of the tracer in tumor sections closely correlates with the hypoxia-induced reporter gene expression. In addition, pO2 data obtained with probes are roughly correlated with PET image information. **Conclusion**: Our results validated the use of PET imaging with members of the 2-nitroimidazole family for identifying tumor hypoxia.

Educational Objectives:
1. The significance of tumor hypoxia
2. PET imaging of tumor hypoxia
3. Use of reporter genes in molecular imaging

Therapy Scientific Session Room 617
Clinical Measurements I

MO-D-T-617-01

Measurement of In-Air Output Ratios for a Linear Accelerator with and Without the Flattening Filter

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Purpose: In-air output ratios (S_c) for photon beams from linear accelerators describe the change of in-air output as a function of the collimator settings. The physical origin of in-air output ratios is mainly due to the change in scattered radiation that can reach the point of measurement as the geometry of the head changes. The flattening filter and primary collimator are the major sources of scattered radiation. The change of amount of backscattered radiation from the collimator into the monitor ion chamber also contributes to the variation of output. To have a better understanding of the contribution of various components to S_c, we measured S_c and backscatter factor S_b for a linear accelerator with and without flattening filter. **Method and Materials:** In-air output ratio (S_c) measurements were carried out with a Farmer type ion chamber in a mini-phantom at 10 g/cm^2 depth for 6 MV and 18 MV x-ray beams from a Varian 2000EX linear accelerator. Backscatter factor (S_b) were measured with a universal pulse counter and a diode array with build-in counting hardware and software. The scatter component S_h was then derived from the relation, $S_c = S_h \times S_b$, where S_b was the linear fit of measured results. **Results:** Significant differences are observed for S_c with and without the flattening filter. Within experimental uncertainty, the backscatter factors, S_b, are similar with and without the flattening filter. There are significant differences in variations of S_h over the range of field size 3x3 to 40x40 cm^2 with and without the flattening filter; for 6 MV it is 8% versus 3%, and for 18 MV 7% versus 1%. **Conclusion:** By analyzing the backscatter contribution and total in-air output ratios with and without flattening filter, we gained insight on contributions of different components to the total variation of S_c.

MO-D-T-617-02

Measurement of Photon and Neutron Doses Outside the Treatment Field for Prostate Patients Undergoing 18 MV IMRT

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Purpose: For IMRT treatments 6 MV photons are typically used, however, for deep seated tumors in the pelvic region, higher photon energies are increasingly being employed. IMRT treatments require more monitor units (MUs) to deliver the same dose as conformal treatments, causing increased secondary radiation from leakage and scatter, as well as a possible increase in the neutron dose from photon interactions in the machine head. Here we provide in-vivo and phantom measurements of the photon secondary radiation and the neutron dose equivalent for 18 MV IMRT treatments. **Method and Materials:** We use different detectors with various photon and neutron sensitivities: TLD 600 and TLD 700 chips, a Neutrak detector containing Al₂O₃ to detect photons using optically stimulated radiation and a CR-39 plastic sheet using track etching for neutrons from Landauer, and a separate CR-39 detector from Argonne National Labs. In –vivo patient measurements were obtained outside the field edge for 9 prostate patients undergoing 18 MV IMRT on two different commercial accelerators. We also compared the secondary photon dose for 6 prostate patients undergoing 6 MV IMRT with that for 18 MV IMRT. Additionally, a 25.4 cm diameter Bonner sphere containing TLD 700 and

TLD 600 was used to compare the out of field secondary doses for typical 18 MV IMRT and 18 MV six-field conformal prostate treatments. **Results:** The patient measurements showed photon doses approximately 12 and 7 times greater than the neutron dose equivalent at 10 and 20 cm from the field edge, respectively. Initial Bonner sphere measurements showed neutron doses for IMRT greater than for conformal treatments. **Conclusion:** For prostate treatment the photon secondary dose for 18 MV and 6 MV IMRT are similar, and the neutron dose is higher than the dose from 18 MV conformal treatments by about the ratio of MUs.

MO-D-T-617-03

Secondary Neutron Spectra From High Energy IMRT and Conventional Treatment Plans Using Bonner Spheres and Au-197 Activation Foils

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Purpose: The purpose of this work is to measure and compare secondary neutron spectra both in-field and out-of-field from the delivery of high energy IMRT and conventional radiation therapy. Direct measurement of neutron spectra in phantom for IMRT has received little attention. Studies are needed to demonstrate the strength of the assumption that the spectra are the same for IMRT and conventional radiation therapy. **Method and Materials:** ^{197}Au activation foils are placed on the surface of a special holder which is inserted into different Bonner Spheres. Seven levels of moderation were used: the bare foil holder and the holder inside 2", 3", 5", 8", 10", and 12" spheres. Net counts of the 411keV gamma peak were measured for each foil using a high purity Germanium detector with spectral analysis capabilities. The activity at the end of irradiation, and the production rate per unit mass of target ($Bqs^{-1}g^{-1}$) were calculated. Data were unfolded with MXD_FC33 algorithm, PTB (Germany) with a response matrix specifically calculated for this measurement system using MCNPX. The response matrix was verified by unfolding ^{197}Au-Foil Bonner Sphere system data from irradiations with ^{252}Cf. **Results:** The unfolded neutron spectra and neutron flux are evaluated. Ambient Dose Equivalent, H*(10) is calculated from spectral data. The data show an increase in the secondary neutron flux and H*(10) for IMRT compared to conventional radiotherapy. The IMRT spectra show a small shift to lower energies. Ratios of in-field to out-of-field flux for 18MV fall off approximately with the inverse square. The ratios of 18MV to 15MV IMRT and conventional out of field flux are 2.13 and 2.6, respectively. **Conclusion:** ^{197}Au activation foils inside Bonner spheres technique for the measurement of neutron spectra inside the treatment room is an effective tool for the determination of neutron spectra from IMRT and conventional radiation delivery.

MO-D-T-617-04

Determination of Midplane Fetal Doses Arising From Distant Sites Treated Via Typical Helical Tomotherapy IMRT

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Purpose: To determine the fetal dose arising from a typical helical tomotherapy IMRT treatment delivered at anatomical sites distant from the embryo/fetus. **Method and Materials:** An anthropomorphic phantom (Rando™ slices 1-25) with the pelvis section replaced by a plastic water™ phantom was used to develop a treatment sinogram with the Hi-Art™ device using typical parameters: 6 MV photons, 2.5 cm field width, pitch of 0.3, and modulation factor of 2. Target dimensions were 8 cm (W) x 7 cm (H) x 11 cm (L) and was centrally located in the abdominal region of Rando™, which was planned and treated to a dose of 5 Gy. Fetal dose measurements were made at a midplane depth of 10 cm in the plastic water using TLD and a calibrated diode. Four sites in Rando™ were treated using the same sinogram allowing the fetal dose to be determined as a function of distance from the treatment site center, which varied from 23 cm to 75 cm. To express results as a percent of the delivered dose for the same sinogram, an approximate correction was made to account for differences in tissue thicknesses at the various treatment sites. **Results:** For the same sinogram delivery (of approximately 5 Gy), fetal dose varied from 3.53 cGy for a lower abdominal treatment at a distance of 23 cm to 0.23 cGy for a brain/head treatment at a distance of 75 cm. A power law fit indicates fetal dose is proportional to the distance to the -2.3 power. **Conclusion:** Typical helical tomotherapy treatments at distant sites may yield fetal doses approaching 1 percent of delivered dose; and fetal dose is reduced by more than the square of the distance to the treatment site. **Conflict of Interest:** A collaborative research relationship is currently being developed with TOMOTHERAPY, Inc.

MO-D-T-617-05

Fetal Doses Measurements for Helical Tomotherapy

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Purpose: According to AAPM Report 50, there are in excess of 4000 women per year that require radiotherapy. In the past ten years, the technology of radiation therapy has advanced considerably with the advent of IMRT and IGRT. The purpose of this work was to measure fetal doses on a helical tomotherapy delivery system. **Method and Materials:** A water-equivalent phantom was constructed for measuring the dose outside of a helical tomotherapy treatment field. The phantom was 60-cm in total length, and the thickness varied from 15 to 17-cm. The phantom was divided into four sections: (1) Head, (2) Shoulders, (3) Torso, and (4) Pelvis. Absolute measurements were taken inside the pelvis section following the TG-51 protocol with a farmer chamber at depths of 1.5, 5.0, and 10.0-cm. Measurements were taken with distance from the chamber to the bottom edge of the field set to 5, 10, 15, 20, and 25-cm. **Results:** The Tomotherapy fetal doses are substantially larger (4.3% verses 1.4%) at 5-cm from the field edge. However, the fetal doses from APPA and helical tomotherapy treatment delivery are within 1 percent beyond 10-cm from the field edge. This is particularly surprising given that the MUs are over a factor of 10 larger for the tomotherapy delivery. The reason is that the head leakage component in the tomotherapy delivery system is much less than a conventional linear accelerator due to the 20-cm of tungsten shielding in primary jaws, the multi-leaf collimator, and head shielding. **Conclusion:** The dose to the fetus on a helical tomotherapy system is within 1% of the fetal dose from conventional APPA delivery. Depending on the total dose and the distance to the fetus, pregnant patients could receive a highly modulated and conformal treatment delivery without exceeding fetal dose tolerance.

MO-D-T-617-06

Contralateral Breast Dose in Conventional and Intensity Modulated Radiotherapy

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Purpose: Induction of secondary malignancies in the contralateral breast can be considered a significant risk of breast radiotherapy due to the excellent prognosis for breast cancer patients and the relative radiosensitivity of the breast. The magnitude of the absorbed dose to the contralateral breast is a primary risk factor for such secondary malignancies. This dose may be reduced by eliminating beam modifiers such as wedges and compensators or by shielding the contralateral breast. **Method and Materials:** We added wax breasts to an anthropomorphic phantom and prepared CT-based treatment plans for five techniques: paired wedges, lateral wedge only, individually-fabricated physical compensators, and both forward-planned and inverse-planned segmental multileaf collimator delivered IMRT. These techniques were administered both without shielding and using lead shields of two different thicknesses (1/8" and 1/4") covering the entire contralateral breast. TLD and ionization chamber measurements were performed at four points inside the contralateral breast, and TLD measurements were performed at five points on the surface of the contralateral breast for each technique. **Results:** With or without the use of shielding, forward-planned IMRT resulted in the lowest dose, followed by inverse-planned IMRT, lateral wedge only, paired wedges, and compensators. The use of forward-planned IMRT resulted in reductions of approximately 45% and 70% in the average surface and internal doses, respectively, in comparison to paired wedges. The use of a ¼" lead shield resulted in additional reductions of 70% and 13% in average surface and internal doses, respectively, for forward-planned IMRT delivery. **Conclusion:** While the clinical superiority of IMRT over conventional radiotherapy for breast cancer is still debatable, the ability of IMRT to reduce the absorbed dose to the contralateral breast is

unequivocal. Furthermore, combined use of IMRT and relatively thin lead shielding can reduce the dose to the surface of the contralateral breast by roughly 85%.

MO-D-T-617-07

Measurements of Surface Dose for 6MV and 10 MV X-Ray Beams Using Micro-MOSFET and Comparisons to Monte Carlo Skin Dose Calculations

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Purpose: Accurate measurement of skin dose in radiation therapy is of considerable clinical importance, especially in treating head-and-neck and breast cancers. MOSFET dosimeters have been introduced as a more efficient and easier-to-use alternative to TLD and radio-chromic film for skin dose measurement. However, existing data with standard-size MOSFET suggest large differences from TLD or film measurements. We investigated the applications of a micro-MOSFET for skin dose measurements and studied the correlation between the measured surface dose by micro-MOSFET and the skin dose expected from a Monte Carlo calculation. **Method and Materials:** 1). Measurements were conducted for normally incident 6MV and 10MV beams onto a flat solid water phantom. MOSFET data were compared with both measurements using a parallel plate ion chamber and a MC dose calculation for the build-up region. 2). Measurements of surface dose were conducted for 6MV oblique beams incident onto the surface of a semi-cylindrical solid water phantom. Results were compared to a MC calculated dose in a skin layer extending 2mm down from the surface. **Results:** For normal beam incidence, depth doses measured by micro-MOSFET agree within 3% with parallel-plate ion chamber data and MC calculation; In the build-up region, comparison of MOSFET data with the MC calculation suggests that the MOSFET has a water-equivalence thickness of ~0.5mm. For oblique beams incident on the curved phantom, the micro-MOSFET measurements correlate well with the MC calculated skin dose for a 6 MV beam, with up to ~ 6% differences depending on the positions of the MOSFET on the surface. Results from a 10 MV beam will also be presented. **Conclusion:** Preliminary results indicate that the measured surface dose with a micro-MOSFET on a curved surface under a 6MV oblique beam irradiations provide a good approximation (within ~ 6%) of the skin dose.

MO-D-T-617-08

Skin Dose Measurement with Radiochromic Film

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Purpose: Due to the build-up properties of megavoltage x-ray beams, skin dose varies significantly within the first few millimeters of the skin depth. The practical measurement depth depends on equipment type and design and the biological effect one is interested in. The skin depth recommended for practical skin dose assessment is at 0.07 mm depth according to the ICRP 26 and the ICRU 39. The goal of our study was to determine the correction procedure in order to obtain an accurate skin dose at the depth of 70 microns, for 6 MV photon beams using different GafChromic film models. **Method and Materials:** We used new GAFCHROMIC ® film models, HS, XR-T, or EBT which have effective points of measurement at depths slightly higher than 70 microns. Film pieces were exposed to 6 MV photon beams placed at the surface of solid water phantom. In addition to the films, we also used Attix plane parallel chamber and extrapolation chamber in order to cover tissue equivalent depths in the range from 10 microns to 1 mm. **Results:** Our measurements suggest that within the first millimeter of the skin region, the PDD for 6 MV photon beam and field size of 10 cm x 10 cm increases from 14 % to 40 %. **Conclusions:** For the three different GafChromic film models, 6 MV beam skin dose corrections are: 12% for EBT, 15% for HS and 16 % for XR-T model GafChromic films.

Therapy Scientific Session — Room 6E
Radiobiology

MO-D-T-6E-01

A Computational Analysis of Lung Damage From 3D, IMRT, and Helical Tomotherapy

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Purpose: It is well known that the lungs are extremely sensitive to radiation damage. Based on low-dose tolerance models, the argument has been made that delivering small doses from multiple gantry angles may actually cause more lung damage than delivering large doses from fewer gantry angles. The purpose of this work is to calculate the percent reduction in lung function for several existing lung models and treatment delivery techniques. **Method and Materials:** Conformal APPA, non-coplanar 3D conformal, and helical tomotherapy plans were created for 15 lung patients. All plans used the same beam energy, the PTV, and prescribed dose. The percent reduction in lung function was calculated by multiplying the DVH doses by a dose response function. Three published models were used: 1.) Lung function reduces linearly at 1% per Gy (*Linear*), 2. Lung function reduces to 0% at the threshold dose of 13 Gy (*Delta13*), and 3.) Lung function decreases to 0% at the threshold dose of 36 Gy (*Delta36*). **Results:** The linear model yielded the least difference in lung function reduction between the three delivery techniques, with a mean difference of 3 percent (*range 1-7%)*. The delta13 model clearly favors APPA treatment delivery, with the exception of targets smaller than 50cc. If the threshold for lung damage is greater than 20 Gy, then the conformal techniques overtake APPA in providing the least lung damage. A delta36 model greatly favors highly conformal rotation delivery techniques, such as tomotherapy. **Conclusion:** Although the model for lung damage is unknown, several conclusions can be draw on the appropriateness of delivery techniques. If the threshold for damage is at very low doses, then techniques that spread the dose are less advantageous. However, if the threshold is greater than 20 Gy, or is linear, then conformal techniques provide the best lung sparing.

MO-D-T-6E-02

Dose-Response Explorer: An Open-Source-Code Matlab-Based Tool for Modeling Treatment Outcome as a Function of Predictive Factors

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Purpose: Radiotherapy treatment outcome models are a complicated function of treatment parameters and/or clinical factors. Our objective is to provide clinicians and scientists with an accurate, flexible, and user-friendly tool to explore radiotherapy outcome models with different factors leading to tumor control or normal tissue complications. We refer to this tool as the dose response explorer (DREX). **Method and Materials:** DREX, based on Matlab named-field structures, provides tools for multi-term logistic regression modeling, correlation calculations, and graphical comparisons between model predictions and observations. A GUI-driven interface was constructed using Matlab tools. Named-field structures in Matlab support development of very human-readable databases **Results:** The DREX tool provides the NTCP or TCP analyst with multiple features which include: (1) Combination of multiple dose-volume variables (mean dose, max dose, Vx (percentage volume receiving x Gy), Dx (dose to x percentage volume), EUD (equivalent uniform dose), etc) and clinical factors (age, gender, ethnicity, etc), (2) Model analysis using logistic regression, (3) Performance assessment using Spearman's rank correlation and receiver operating characteristics (ROC) curves, and (4) Graphical capability to visualize NTCP or TCP prediction versus selected variable model using contour and histogram plots. DREX has been in constant use in our research group for the last nine months. **Conclusion:** We developed user-friendly software to explore and model radiotherapy dose-response correlations. DREX facilitates convenient study of different treatment and clinical factors which may correlate with complication or control. We believe that the DREX software combined with CERR archiving would provide the clinical researcher with convenient tools to accrue and model radiotherapy outcomes data. DREX will be freely distributed via the web. We expect to continue developing DREX, including adding methods to

automatically select model terms, find the optimal model size, and estimate parameter uncertainties.

MO-D-T-6E-03

IMRT Vs. 3D-CRT for Oropharyngeal Cancer: Relative Sensitivity to Set-Up Uncertainty

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Purpose: To compare the impact of set-up uncertainty on compliance with the objectives and constraints of the RTOG H-0022 protocol using an IMRT plan versus a conventional 3D-CRT plan. **Method and Materials:** Two treatment plans (7 beam IMRT and 4 beam 3D-CRT) were created using Pinnacle® for the same volumetric data set based on the objectives and constraints defined in the RTOG H0022 protocol. Dose volume constraints for the targets and organs at risk (OARs) were met and matched as closely as possible in both plans. Monte-Carlo based simulations of set-up uncertainty were performed in three orthogonal directions for "simulated courses" incorporating systematic and random uncertainties. A population based approach was used to compare the IMRT and 3D-CRT plans in terms of Dose-Volume Histograms (DVHs) and Equivalent Uniform Doses (EUDs) **Results:** Based on DVH and EUD data, the compliance of the delivered treatment with the objectives defined for the CTV66 and CTV54 shows considerably greater sensitivity to set-up uncertainty for the IMRT plan than for the 3D-CRT. Three of the OARs defined in this study (larynx, spinal cord, and brainstem) continue to meet the criteria in the presence of set-up uncertainties for both plans. Dose constraints for the mandible were not met for the 3D-CRT and neither was parotid sparing possible. The static IMRT plan was able to meet the criteria for parotid sparing. However, even at relatively low levels of set-up uncertainty, parotid sparing was compromised in the IMRT protocol. **Conclusion:** The IMRT plan target doses are more sensitive to set-up uncertainty than the 3D-CRT when looking at both the DVHs and EUDs. In the presence of reported levels of set-up uncertainty, parotid sparing is compromised in the IMRT plan. However, parotid doses always remain lower than those seen with the 3D-CRT plan.

MO-D-T-6E-04

On the Dose-Volume Constraints Based On Radiobiological Considerations

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Purpose: To apply radiobiological principles in the estimation of dose-volume constraints used in treatment planning. To evaluate NTCP distributions affiliated with certain multiple dose-volume constraints. To estimate the probability $P_{mD\text{-}V}$ that a dose-volume histogram resulting in a given NTCP level also satisfies certain multiple dose-volume constraints. **Method and Materials:** The reverse NTCP mapping method[1] is used here to obtain physical dose-volume constraints based on radiobiological indices. A procedure for random integral DVH sampling from the space of monotonously decreasing functions is developed. DVHs are randomly simulated and the ones producing an $NTCP \in \{5 \pm 0.5\%\}$ are selected. An average DVH is produced from the selected DVHs. We propose that any point from the averaged DVH may serve as a physical dose-volume constraint. A Monte-Carlo method is used to estimate the probability $P_{mD\text{-}V}$ for a number of these constraints. **Results:** Dose volume constraints for 16 organs selected based on the availability of parameter estimates for the Lyman and the Critical Volume NTCP models[2,3] are obtained. The Emami[4] constraints lay on the "upper boundary" of the DVH sub-space defined by the condition NTCP=5±0.5%. The calculated probabilities $P_{mD\text{-}V}$ are very low, indicating that the physical optimization uses a much smaller subspace of the possible solutions than the biological or the physico-biological optimization. **Conclusion:** New dose-volume constraints based on radiobiological considerations are proposed. DVHs passing through a combination of constraints[1] are outside the range of the DVHs producing NTCP=5±0.5%. The physical RT optimization is more restricted in its choice of solutions than the biological one.

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MO-D-T-6E-05

Biological Optimization of Fractionated IMRT Using Fraction Groups

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Purpose: To describe software for biological optimization of fractionated IMRT where the fluence profiles are not restricted to be identical for all fractions and to investigate the impact of fractionated time-dependent response functions on the optimization result. **Method and Materials:** If the fluence profiles of all beams in every fraction are optimized the number of variables is proportional to the number of fractions. Each new fraction consumes memory and slows down the optimization. In order to reduce the number of variables similar fractions are assigned to the same fraction group. The same fluence profile is delivered for every fraction in a fraction group. To test the method the Poisson-LQ model is extended with a time-dependent bi-exponential repair model. **Results:** In all tests the NTCP was minimized while the TCP was kept constant. If the time between consecutive fractions is long enough to cause complete repair there is not much gain in optimizing several fraction groups. In the case of incomplete repair, the NTCP was reduced by assigning Monday morning and Friday afternoon to a second fraction group. Adding more fraction groups did not improve the response significantly. **Conclusion:** The use of fraction groups enables an efficient implementation of IMRT-optimization of a fractionated treatment and makes it possible to study time-dependent biological models. In the case of Poisson-LQ with repair, two fraction groups can improve the biological response. This is only true in the case of incomplete repair and the impact of the fractionation depends on the repair half times. **Conflict of Interest:** Some of the authors are employees and some are stock owners of the submitting company.

MO-D-T-6E-06

In Vitro Measurement of the Repair Time for Prostate Cancer

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Purpose: It is concerned that the prolonged delivery time of IMRT may affect the treatment effectiveness. For prostate cancer, biological modeling suggests that the effectiveness of IMRT could be degraded by over 10% when the repair half-time is short compared to the fraction delivery time. Published data show that repair half-time for prostate cancer may be as short as 10 minutes or as long as a few hours. The purpose of this study is to measure the repair half-time of prostate cancer cells with split-dose experiments *in vitro*. **Method and Materials:** We performed a series of single-fraction and split-dose experiments with the DU-145 cell line, which is derived from human prostate cancer, and analyzed the data using the linear-quadratic (LQ) model. The study is presented in two parts: (1) estimate the LQ parameters (α and α/β) from high-dose-rate survival data (0 to 12 Gy) and (2) determine the repair half-time from split-dose experiments (4 Gy + 4 Gy and 6 Gy + 6 Gy) with time intervals ranging from 6 minutes to 8 hours. **Results:** Preliminary analysis of our pilot data shows that DU-145 cells are very radiosensitive with a large α/β ratio (α = 0.52 Gy^{-1} and α/β = 11.5 Gy). The repair half-time derived from the split-dose data is 18 minutes and the estimated standard confidence interval is between 16 to 19 minutes. No component of repair half-time over one hour has been detected. **Conclusion:** The sublethal damage repair of DU-145 prostate cancer cells is very rapid with a repair half-time less than 20 minutes, which is consistent to the repair half-time of 16 minutes derived from clinical data in a previously reported study. Our preliminary results needs to be verified in the follow-up experiments.

MO-D-T-6E-07

Radiosensitivity Parameters for Aerobic and Hypoxic Cells Are Related by a Simple Formula

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Purpose: Cells irradiated in an aerobic environment are much more

sensitive to radiation than hypoxic cells. Although some new imaging modalities have the potential to provide information about the spatial distribution of hypoxic cells within a tumor, the question of how much additional dose must be delivered to hypoxic tumor regions to improve local tumor control requires estimates of intrinsic radiosensitivity parameters. Mechanistic considerations suggest that linear quadratic (LQ) parameters for hypoxic and aerobic conditions are related by $\alpha_H = \alpha_A / f$ and $(\alpha/\beta)_H = f \cdot (\alpha/\beta)_A$, where f is the ratio of DNA damage formed under aerobic to hypoxic conditions. *In vitro* cell survival data for five cells are used to examine the validity of the proposed expressions. **Method and Materials:** Estimates of α_H and $(\alpha/\beta)_H$ derived from a weighted least-squares fit to the survival data for hypoxic conditions are compared to estimates obtained from a three parameter [f, α_A and $(\alpha/\beta)_A$] fit to data for aerobic and hypoxic conditions. The paired bootstrap technique for regression is used to compute 95% confidence intervals on parameter estimates**. Results:** For all five cell lines, good fits to the survival data are obtained with values of f between 2.3 and 3.3. The estimated range for f is strikingly similar to the oxygen enhancement ratios reported in the literature for many types of DNA damage. The value of f also decreases as particle LET increases, as expected. **Conclusion:** Analysis of the *in vitro* survival data provides strong support for the hypothesized relationship between LQ parameters under aerobic and hypoxic conditions. The studies also suggest the intriguing possibility that radiosensitivity parameters for hypoxic cells can be estimated from parameters for aerobic cells (or vice versa) by introducing a single parameter (f) that is nearly independent of cell type.

MO-D-T-6E-08

Derivation of the Relative Biological Effectiveness of High Dose Rate 252Cf Brachytherapy

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Purpose: While there is significant clinical experience using both low- and high-dose rate (HDR) ^{252}Cf brachytherapy, there is minimal data regarding values for the neutron relative biological effectiveness (RBE) with both modalities. The aim of this research was to derive a radiobiological model for ^{252}Cf neutron RBE and to compare these results with neutron RBE values used clinically in Russia. **Method and Materials:** The linear-quadratic (L-Q) model was used as the basis to characterize cell survival following irradiation, with identical cell killing rates ($S_N = S\gamma$) between ^{252}Cf neutrons and photons used for derivation of RBE. Using this equality, a relationship among neutron dose and L-Q radiobiological parameter (i.e., α_N, β_N, α_γ, β_γ) was obtained without need to specify the photon dose. These results were used to derive the ^{252}Cf neutron RBE which was then compared with Russian neutron RBE values. The ^{252}Cf neutron RBE was determined after incorporating the L-Q radiobiological parameters obtained from cell survival studies with fast neutrons and teletherapy photons. **Results:** For single-fraction HDR neutron doses of 0.5, 1.0, and 1.5 Gy, the total (neutron plus photon) doses were 3.5, 6.0, and 8.1 Gy, with ^{252}Cf neutron RBE values of 6.4, 5.5, and 4.9, respectively. Russian clinicians obtained HDR ^{252}Cf neutron RBE values ranging from 7 to 3 for similar doses and fractionation schemes, and observed that ^{252}Cf neutron RBE increases with the number of fractions and is dose rate dependent. A value of 5 was obtained for HDR ^{252}Cf neutron RBE. **Conclusion:** The methodology presented herein presents a reasonable technique to utilize well-characterized radiobiology parameters from radiation sources having similar radiobiological properties towards obtaining calculated values for RBE. Using these relationships, results were in general concordance with ^{252}Cf RBE values obtained from Russian clinical experience.

MO-D-T-6E-09

Progress Towards a MicroRT Small Animal Conformal Irradiator

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Purpose: Newly developed small animal imaging devices, like micro computed tomography (microCT), micro positron emission tomography (microPET), and micro magnetic resonance (microMR), have stimulated development of small radiation therapy devices - microRTs. A conformal small animal irradiator will provide customized dose distributions that enable the investigator to limit confounding side effects and obtain more quantitative response results. **Method and Materials:** The first step towards designing the microRT irradiator was to perform Monte Carlo simulations to aid in optimization of the proposed design. The proposed irradiator uses a high activity ^{192}Ir source that is a relatively small (*3mm* long and *3mm* in diameter) cylinder. The BEAMnrc Monte-Carlo code for was utilized to model the dose distribution for three source-to-target distances: *60mm*, *70mm* and *80mm*, and five circular field sizes: *5mm*, *7.5mm*, *10mm*, *12.5mm* and *15mm*. Finally, dose to a *50 x 50 x 50mm*^{3} water phantom with *1 x 1 x 1mm*^{3} voxel spacing was computed. To provide rapid dose calculations for treatment planning, a parametric dose model was developed and fit to the Monte Carlo data. **Results:** The simulated radiation beams were determined to be radially symmetric, so a radially symmetric parametric form was selected for the dose model. The depth dose distribution was dominated by the inverse square law and the beam profile and depth-dose fits were excellent. The parameters varied smoothly as a function of depth, source-to-surface distance, and field size, allowing interpolation for non-simulated geometries. **Conclusion:** Preliminary results of Monte-Carlo simulations demonstrated that the parametric fit to the dose distribution of a ^{192}Ir microRT device provides good agreement with Monte Carlo predictions.

Workshop Room 608

Display Evaluation Demonstration Workshop

MO-D-W-608-01

Display Evaluation Demonstration Workshop

E Samei*, Duke Univ, Durham, NC

The AAPM TG18 is a new initiative aimed to provide standard guidelines and procedures for acceptance testing and quality control of electronic display devices for medical applications. The recommendations, based on the newly-designed TG18 test patterns, include detailed visual and quantitative methods and specific acceptance criteria for objective assessment of display quality using the TG18 standard test patterns and specified equipment. The display characteristics considered include luminance, luminance spatial and angular response, resolution, noise, veiling glare, reflection, color uniformity, geometrical distortions, and display artifacts. The goal of this demonstration workshop is to present a tutorial and demonstration on practical aspects of display set up and display performance evaluation based on the TG18 methodology. Representatives from the TG18 committee and from industry will be present to demonstrate and discuss display evaluation issues.

Participants:
Jeffrey Charette, Barcoview, LLC
Ehsan Samei, Duke University Medical Center
Noriyuki Hashimoto, Eizo Nanao Corporation
Dave Sorensen, Image Systems Corporation
Kenneth Compton, National Display Systems
Adi Abileah, Planar Systems
Hans Roehrig, University of Arizona

Professional Session Room 618

Report from Committee on Alternate Training Pathways

MO-D-P-618-01

Update From the President's Adhoc Committee On Alternative Paths to Medical Physics Residency Training

L Reinstein*[1] , M Herman*[2] , (1) SUNY Stony Brook, Stony Brook, NY, (2)Mayo Clinic, Rochester, MN

We all support the fundamental philosophy that both a thorough groundwork in physics and *structured clinical training* is essential for individuals who will be involved in the practice of clinical medical physics. A structured clinical training program, such as a CAMPEP accredited medical physics residency, followed by board certification (by the ABR or equivalent) provides the mechanism for people with graduate degrees in various technical (physics) fields to acquire and demonstrate clinical competency. As reported in the April Point Counter Point by Amols and Herman, graduates of CAMPEP accredited residency programs pass the

full ABR on the first attempt at a 95% rate, whereas the average ABR taker passes at 53%. Under current and foreseeable market conditions however, the demand for qualified medical physicists far exceeds the supply of individuals being produced by existing accredited programs. There are currently 11 (10 Therapy, 1 Imaging) accredited residency programs (with ~5 under consideration). A back of the envelope calculation suggests that approximately 50 accredited residency programs would be required to support the current demand. Thus, in the short run (and to provide a jumpstart for additional qualified trainees), alternate pathways must be developed to insure an adequate supply of clinical medical physicists while at the same time insuring academic excellence, diversity, and clinical competency. The question remains: how can we establish a mechanism that produces enough qualified people, without creating a huge financial burden or an unrealistic set of conditions that few individuals can meet. Providing the mechanism to bring medical physicists into practice who are properly prepared to discharge clinical duties in the patient care setting is a very high priority.

The concept of CAMPEP accredited *structured mentorship* programs could provide a viable and high quality pathway for training future clinical medical physicists of various backgrounds. A proper and thorough pathway for training a clinical medical physicist has three essential components:

1. *A graduate degree* in medical physics, physics, (or equivalent – this may need discussion).
2. *Clinical training in a CAMPEP accredited clinical training program.* This means either a clinical residency in one of 11 accredited programs or a structured mentorship (accredited by CAMPEP). In the structured mentorship, the idea is that a junior physicist (or some other trainee) could be entered into training under the guidance of a CAMPEP accredited mentor. The mentor is responsible for delivering the training consistent with AAPM report 36 and documenting it.
3. *Sit for the ABR or equivalent exam*. The ABR must accept only candidates who have been trained in these CAMPEP accredited programs, be it a residency, or the structured mentorship. ABR has stated this is a goal for 2012 and we should strongly support this goal.

Issues and caveats:

1. How do we address graduates from CAMPEP accredited MS and Ph.D. programs? Do they get a break? They still need documented clinical training. However, if one comes from a CAMPEP accredited graduate program, some advanced placement may be given in the residency training process for those items in report 36 already achieved and documented.
2. It is also understood that not all facilities can offer training in all aspects of the practice as outlined in AAPM report #36. In such cases, the mentor (and trainee) is required to develop relationships with other training facilities that would provide and document the needed supplemental education to complete the requirements of the training program.
3. Mentors of the structured programs would be evaluated and reviewed in the same way and at the same frequency as accredited residency programs. A mentor could be deferred, denied accreditation by the same process in place at CAMPEP for current residency programs. CAMPEP should be encouraged to accomplish this.

Without such expanded and structured pathways to qualified clinical practice, we will continue to experience a shortage of competent clinical medical physicists, who will do poorly on the certification exam, give medical physics a bad name and worst of all increase the possibility of harming patients.

Educational Objectives:

1. To review the essential components of a thorough clinical medical physics training pathway
2. To discuss alternative pathways to help provide sufficient competent medical physicists who have followed the defined structured pathway.

Imaging Scientific Session Room 609
Advances in Breast Imaging

MO-E-I-609-01
Evaluation of Scattered Radiation Effect On Breast Cone-Beam CT Image: A Phantom Study

A Kwan*, J Boone, K Yang, N Shah, Department of Radiology, UC Davis Medical Center, Sacramento, CA

Purpose: To quantify the impact of scattered radiation on CT image reconstruction. **Method and Materials:** A 14 cm diameter cylindrical 50/50 (50% glandular/50% adipose) tissue equivalent phantom was used to assess CT scatter conditions in a custom build cone-beam breast CT scanner. The amount of scatter was varied by controlling the vertical dimension of the collimator opening (in the cone angle direction), which ranged from 16.8 to 100.2 mm at isocenter. Four data sets were acquired for each collimation, two with a 50/50 tissue equivalent rod and two with a 100% glandular tissue equivalent rod at the center of the phantom, with a scan technique of 80 kVp, 5 mA and 16.6 s (500 views). The images were reconstructed at the exact location for all the different collimated images, and the *CNR* was used to assess the image quality as a function of scatter to primary ratio (*SPR*). **Results:** As the amount of scatter (collimator gap) increases, the cupping artifact in the reconstructed image increases slightly. The *CNR* dropped from 2.6 at 16.8 mm collimation to 2.0 at 22.5 mm collimation, and remained at about 2.0 with further increases in the gap's width. **Conclusion:** Based on the preliminary results presented here, the scatter radiation increased the cupping artifact in the reconstructed image and reduced the *CNR*. However, the reduction in *CNR* appears to occur most dramatically at lower *SPR* and does not worsen significantly as the scatter increases from moderate (SPR = 0.1) to high (SPR = 0.5) levels.

MO-E-I-609-02
Imaging Properties of Cone Beam Breast CT- Effects of Detector Properties and Imaging Conditions

C Shaw*, L Chen, M Altunbas, T Wang, C Lai, S Tu, X Liu, S Kappadath, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: To investigates the effects of detector properties and imaging conditions on the imaging properties of cone-beam breast CT with both computer simulations and imaging experiments. **Method and Materials:** Cone beam breast CT was simulated with the breast analytically modeled as cylinder embedded spherical shape soft tissue masses and calcifications. X-ray spectrum, breast attenuation, geometric magnification, focal spot blurring, x-ray detection, detector blurring, image pixelization and digitization were all incorporated in computing the projection images. Quantum noise, system noise, detector blurring were also simulated and incorporated in the model. Image filtering and reconstruction were then performed using the Feldkamp algorithm. Simulation was performed for two flat-panel detectors, one CsI based and the other a-Se based. Images of phantoms and breast specimens were also obtained to demonstrate the ability of our experimental cone beam breast CT system to image the 3-D structures of the breast with embedded cancers and calcifications. **Results:** Our simulation results shows that the a-Se detector performs slightly better at 30 and 40 kVp's while the CsI detector performs better at 50 or higher kVp's. Image SNRs are optimized at 50 and 60 kVp for the s-Se and CsI detector, respectively. Phantom images obtained with our experimental system show that with higher dose and smaller pixel size, calcifications as small as could be resolved. Images of breast specimens show excellent separation between glandular and adipose tissues. The speculated nature of the tumor masses can be clearly seen in selected projection while ambiguous in other projections or in regular mammograms. It was also found that inclusion of surgical clips (used to indicate tumor location) had caused detrimental reconstruction artifacts.

Acknowledgment: This work was supported in part by a research grant EB000117 from the NIBIB and a research grant CA104759 from the NCI.

MO-E-I-609-03
A Volume-Of-Interest (VOI) Scanning Technique for Cone Beam Breast CT

L Chen*, C Shaw, M Altunbas, T Wang, S Tu, C Lai, X Liu, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: To demonstrate that high quality cone beam CT images can be generated within the volume-of –interest (VOI) and to investigate the dose saving with the VOI scanning technique. **Method and Materials:** The VOI scanning technique was investigated using both computer simulation and imaging experiments. To implement the VOI scanning technique, an additional filter is inserted between the x-ray source and the breast. The

filter has a circular or rectangular opening to deliver a higher level x-ray exposure to a selected spherical or cylindrical VOI and a lower level exposure to the region outside the VOI. To prepare for reconstruction, a non-uniform reference image acquired with the VOI filter in but with the object out is used to normalize the projection images and measure the object attenuation only. Since the non-uniform attenuation by the VOI filter is modulating both the reference and projection images, it cancels out in the computed transmittance image. Regular Feldkamp filtered backprojection technique is used to reconstruct the 3-D images. Dose saving factor was estimated by tallying x-rays going through the VOI, thus delivered at high dose level, and dividing the result by the total number of x-rays backprojected to an image voxel. **Results:** Images from both simulation and experimental studies show that during VOI scanning, an exposure reduced by a factor of up to 50 can be delivered to areas outside the VOI without compromising on the accuracy of image reconstruction, allowing for a small VOI in the breast to be imaged with more clarity or lower dose to the rest of the breast. However, dose saving becomes less significant when the distance between the voxel and the VOI decreases.

(This work was supported in part by a research grant CA104759 from the NCI and a research grant EB-00117 from the NIBIB)

MO-E-I-609-04

New Detector for Low Dose Cone Beam Computed Tomographic (CT) Mammography Based On Microchannel Plate Image Amplifiers

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Purpose: It is becoming recognized that tomosynthesis and/or full cone-beam CT mammography may provide more diagnostic information than standard two view projection mammography; however, current flat panel digital image receptors have limitations on image quality and low dose due to excessive lag and detector noise. Maintaining the same or lower total procedure dose can severely restrict the per-view exposure, or the number of views. A new high-resolution detector with adjustable high gain is being investigated to overcome these limitations. **Method and Materials:** A detector design consisting of a CsI x-ray converter, fiber-optic taper, microchannel-plate-based image amplifier with variable gain of 6 orders of magnitude, and optical coupling to a high resolution rapid sequence, low noise, 1024^2-2048^2 matrix pixel CCD camera is being investigated for this application. **Results:** A detector with a 16 cm diameter FOV can be achieved with the capability for total scan times of a few seconds. Additionally, off-center magnification modes of full-field-corrected truncated cone-beam CT are possible involving either geometric or optical magnification to improve spatial resolution. Initial tests of a small field-of-view prototype detector of the proposed design with 1024^2 matrix demonstrated linear response (quantum limited performance) for a range of detector entrance exposures from less than 0.2 microR to greater than 1 mR per view for pixels below 35 microns. **Conclusion:** The proposed detector design has advantages over flat panel detectors of exhibiting virtually no ghosting or lag and of providing more than 10X lower exposure per view capability due to the huge gain dynamic range and low noise available. Further investigations involving optimization of voxel size, number of views, reconstruction algorithm, exposure per view, exposing x-ray spectrum, equalization filters, scatter reduction, patient positioning, and total scan times are proceeding.

(Partial support: NIH grants R01EB002873 and R01NS43924)

MO-E-I-609-05

Volumetric Assessment of Glandularity in Screen-Film Mammography

L Benevides*, L Brateman, D Hintenlang, Gainesville, FL, Univ Florida, Gainesville, FL

Purpose: A clinical dosimetry protocol is developed that utilizes a dosimetric breast phantom series based on population demographics to predict the mean glandular dose (MGD) imparted to the patient during a routine screening mammogram. **Method and Materials:** A dosimetric breast phantom was developed from published data to represent the glandular (67.8%, 42.6%, 25.4%, and 16.2%) and compressed thickness (2, 4, 6, 8 cm) of a cranial-caudal view. In addition, a step phantom was developed which is composed of glandularity and thickness ranging from 0-100% glandular and thicknesses ranging from 1 to 8 cm.
A prospective study composed of 253 women from a screening mammography population with an ACR diagnosis category of 1 or 2. The cranial-caudal (CC) and medial-lateral oblique (MLO) mammograms were digitized and segmented to determine the population mammogram demographics. Glandularity was also determined from radiologist ACR density code, planimetry, tube loading, and volumetric method for comparison. **Results:** The dosimetric breast phantoms had breast thickness and glandularity comparable to published data. The CC and MLO compressed thicknesses and lateral dimensions are extracted from the population data with average compressed thicknesses of 4.46±1.17 cm and 5.21±1.39 cm, respectively. Glandularity determined from a planimetry method resulted in glandularities of 30 ± 16 % and 18 ± 18 % for CC and MLO, respectively. Glandularity based on tube loading was developed using the BRTES-MOD phantom AEC response. The AEC response was fitted to a three dimensional plane correlating compressed breast thickness. Grandularity determined from tube loading method resulted in granularities of 61.94 ± 27.75 % and MLO was 51.19 ± 29.93 % for CC and MLO, respectively. **Conclusion:** The resultant data was used to develop a clinical protocol that correlated pixel intensity from a digitized mammogram to breast glandularity using a volumetric technique.

MO-E-I-609-06

Squared Contrast-Noise Ratio Per Dose and Rh-Filter Thickness for Digital Mammography

T Nishino[1], X Wu[2], R Johnson*[1], (1) Univ Texas Medical Branch of Galveston, Galveston , TX, (2) Univ Alabama Birmingham, Birmingham, AL

Purpose: Increase detection sensitivity of breast carcinoma is greatly needed for digital mammography. We show that the tissue-lesion contrast-noise ratio (CNR) at a given dose level can be improved by increasing the Rh-filter thickness used for the Rh-target in digital mammography.
Method and materials: Currently a 25μm-Rh filtration is the standard in digital mammography for all the modes with a Rh-target. To test if this standard filter-thickness is optimal, we studied how the contrast-noise ratio between breast and infiltrating ductal carcinoma (IDC) of 5mm-size embedded a 6cm-thick breast changes with Rh-filter thickness for Rh-target. We performed imaging experiments by modifying the filter wheel of a GE Senographe 2000D unit with Rh-filters of 25μm, 37μm, 50μm, 62μm and 75μm. Before imaging a phantom the x-ray HVL values at 29 kVp and radiation outputs were measured for each Rh-filter thickness ranging from 25μm to 75μm. A 50%-glandular and 50%-adipose breast phantom of 6cm with an infiltrating ductal carcinoma (IDC)-simulating insert of 5mm in size was used as the phantom for all the cases. The CNR's between the breast phantom and the IDC-insert were measured, and average glandular doses were calculated by using a filtration-dependent x-ray spectra model and a breast-dosimetry model based on a validated Monte Carlo simulation. The exposure times were recorded as well.
Results: In contrast to conventional wisdom, the tissue-lesion CNR at a given dose level increases with increasing Rh-filter thickness from 25μm to 75μm. The measured squared CNR per dose were increased by 7%, 13%, 18% and 21% for 37μm, 50μm, 62μm and 75μm Rh-filters compared to that for the standard 25μm Rh-filter, respectively.
Conclusions: Increasing Rh-filter thickness for Rh-target from 25μm to 50μm can increase tissue-lesion squared CNR per dose by 13% with a tolerable increase of exposure duration.

MO-E-I-609-07

Dual-Energy Digital Mammography for Calcification Imaging: Improvement by Image Processing

S Kappadath*, C Shaw, Dept. of Imaging Physics, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: We have developed and implemented a full-field dual-energy digital mammography (DEDM) technique, with total mean-glandular dose similar to screening-examination levels, to detect and visualize calcifications over tissue structures on mammograms. The suppression of tissue structures by DEDM comes at the cost of increased DE image noise. We report on the effects of image processing techniques on the DE calcification images. **Method and Materials:** To evaluate different image

processing techniques, we have designed a special phantom with calcium carbonate crystals simulating calcifications of various sizes superimposed with a 5 cm thick breast-tissue phantom with continuously varying glandular ratio from 0.0 to 1.0. We report on the effects of three noise reduction techniques: (1) a simple smoothing filter applied to the DE image, (2) a median filter applied to the HE image, and (3) a correlated-noise reduction technique (KNR), where the scaled correlated noise from the DE tissue image was added to the DE calcification image (originally developed for DE computed tomography by Kalender et al., IEEE Transactions on Medical Physics 7, 218, 1988). **Results:** Most calcifications larger than 355 microns were visible in the unprocessed DE calcification image. The simple smoothing filter, although effective in noise suppression, does not improve calcification visibility due to loss of spatial resolution. Calcifications larger than 300 microns were visible with the median filter for kernel sizes of 3 and 5 pixels; while calcifications larger than 250 microns were visible with the the KNR technique for a scale facor of 0.00145 and kernal sizes of 25 and 51 pixels. **Conclusion:** The median and KNR image processing techniques improved calcification visibility while reducing the image noise in the DE calcification images. (Supported in part by research grants DAMD 17-00-1-0316 from the US Army BCRP, CA 104759 from the NCI, and EB000117 from the NIBIB)

Imaging Symposium Room 611
Dual-modality Imaging: From Physics to Physician

MO-E-I-611-01
Introduction to Dual-Modality Imaging and SPECT/CT
B Hasegawa, UCSF Physics Research Laboratory, San Francisco, CA

Over the past decade, dual-modality imaging has emerged as a diagnostic technique which combines structural and functional information with the goal of improving the assessment and management of patients with heart disease, cancer, and other disorders. Prototype dual-modality systems developed by early investigators were designed to perform both x-ray and radionuclide imaging simultaneously with a single detector array, an approach proved to be very challenging and ultimately impractical. Now, both SPECT/CT and PET/CT systems are available for clinical use that integrate separate radionuclide and x-ray imaging subsystems with a common gantry, computer system, and patient table. The direct combination of radionuclide and x-ray imaging with dual-modality systems thereby facilitates fusion of functional and structural image data. In addition, patient-specific *a priori* information from CT can be incorporated into tomographic algorithms used to reconstruct the radionuclide data with corrections for photon attenuation and other physical perturbations, to improve both the visual quality and the quantitative accuracy of the radionuclide data. PET/CT now has significant clinical role in facilitating structural/functional correlation and attenuation correction, primarily of ^{18}F-fluorodeoxyglocuse imaging of patients with cancer. Similarly, SPECT/CT can perform attenuation correction and structural/functional imaging using single-photon diagnostic agents for cancer and heart disease, including those that use gamma-ray emitting radiopharmaceuticals for radionuclide cancer therapy. These applications are enabled through the design and implementation of both the hardware and the software for dual-modality imaging, and provide unique capabilities and important clinical data which can not be achieved easily when structural or functional imaging is performed in isolation.

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Educational Objectives:
1. To understand the design and clinical goals of dual-modality imaging systems, including both SPECT/CT and PET/CT
2. To understand how implementation of dual-modality imaging improves both the visual quality and the quantitative accuracy of radionuclide data

MO-E-I-611-02
PET/CT Imaging: A Physicist's Viewpoint
D Townsend*, University of Tennessee, Knoxville, TN

Despite considerable progress in the treatment of malignant disease, early detection still offers the best chance of a favourable prognosis. For patients with cancer, the anatomical identification of lesions by Computed Tomography (CT) has been used extensively to provide a differential diagnosis, following the onset of clinical symptoms. However, by the time abnormal tissue has grown sufficiently to appear positive on CT, the disease may well have progressed to a stage where successful treatment is, at best, difficult and at worst, impossible. The key is to identify a concentration of cancer cells at the earliest possible stage in the disease development.

In the past few years, Positron Emission Tomography (PET) with ^{18}F-fluoro-deoxyglucose (FDG) has become increasingly widely used to both diagnose and stage malignant disease. Fusion imaging that combines CT and PET obviously offers the best of both worlds: functional abnormalities can be accurately localized with CT and the functional status of anatomical abnormalities can be assessed with PET. While software fusion techniques provide accurately-aligned images of the brain, for the remainder of the body, patient positioning and involuntary internal organ movement present a difficult challenge. The recent introduction of hardware fusion using dual-modality combined PET/CT scanners has resolved many of the difficulties inherent to the software approach. With the combined scanner, the patient remains on the same bed for both CT and PET scans and a simple axial translation of the couch transports the patient from the CT to the PET imaging fields. A single scan session thus provides accurately aligned anatomical and functional image sets.

Even though combined PET/CT scanners have been in production for only four years, the technology is undergoing rapid evolution. For PET, the introduction of new scintillator materials, detector concepts and electronics is resulting in performance improvements in count rate, spatial resolution and signal-to-noise. At the same time, the increasing number of detector rows and reduction in rotation time are transforming whole-body CT performance. The combination of high performance CT with high performance PET is a powerful imaging platform for the diagnosis, staging and therapy monitoring of malignant disease. Over 90% of PET sales are now PET/CT with the prediction that PET-only scanners could be replaced entirely by PET/CT in the future. It is also anticipated that there will be a demand for a mid-range design that offers less performance at less cost. Since the performance of the PET components is the limitation on the overall imaging time, institutions requiring high throughput and large patient volumes will always demand the highest PET performance. Nevertheless, a 4 or 8-slice CT scanner should be adequate for oncology, while a 16 or 64-slice CT will be more appropriate for cardiac applications. As the current PET/CT technology becomes more widespread, appropriate designs implementing this concept will doubtless emerge in the future.

Educational Objectives:
1. Summarize the rationale for combined PET/CT
2. Review recent advances in PET/CT designs
3. Discuss the future potential for the technology

MO-E-I-611-03
Dual Modality Imaging: The Physician's View
T Blodgett*, University of Pittsburgh Medical Center, Pittsburgh, PA

(no abstract submission)

Joint Imaging/Therapy Symposium Room 6B
In-Room Imaging for Therapy Guidance

MO-E-J-6B-01
On the Use of Optically Guided 3D-Ultrasound for Daily in Room Target Localization
W Tome*, N Orton, University of Wisconsin, Department of Human Oncology and Medical Physics, Madison, WI

Purpose: To describe the commissioning, quality assurance and clinical

use of optically guided 3D-ultrasound guided patient positioning systems. **Method and Materials:** To determine the absolute localization accuracy of an optically guided 3D-ultrasound guided patient positioning system an absolute coordinate system using optical-guidance was established and spherical targets at various depths were localized. In order to test the ability of this system to determine the magnitude of an internal organ shift with respect to the treatment isocenter, a phantom that closely mimics the typical human male pelvic anatomy was used. With the phantom on the treatment couch, optical guidance was used to determine the positions of each organ to within imaging uncertainty, and to align the phantom so the plan and treatment machine coordinates coincided. To simulate a clinical misalignment of the treatment target, the phantom was shifted by different precise offsets, and an experimenter blind to the offsets used ultrasound guidance to determine the magnitude of the shifts. In order to assess the inter-user variability of 3D-ultrasound image guidance, four experienced operators determined independently determined the daily organ shifts for the same 5 patients for 5 consecutive fractions. Moreover, in order to assess the extent of prostate motion during the time required to deliver a treatment, ultrasound localization was repeated at the end of treatment for 6 patients for a total of 29 fractions. For all patients treated at our institution for prostate cancer the prostate is immobilized using a rectal balloon. **Results:** The accuracy of the system for localization of spherical targets imbedded in a phantom at depths ranging from 3 to 13 cm was determined to be (average ± standard deviation) AP = 0.2 ± 0.7 mm, Lat = 0.9 ± 0.6 mm, Ax = 0.6 ± 1.0 mm. For the phantom organ motion test the magnitude of the shifts could be determined on average to within 1.0 mm along each axis. The interuser variability was found to be small in comparison to the shifts indicated, showing that these shifts would have been worthwhile making in order to reduce the risk of geographical miss of the target. For the intrafraction prostate motion experiment the post-treatment ultrasound showed a mean prostate shift of 1.9 ± 1.0mm. The shift was within the imaging uncertainty of the system for 25 of the 29 fractions. **Conclusion:** If users are adequately trained in the use of optically guided 3-D ultrasound target localization it can be a valuable tool for aligning patients and allow for the use of reduced margins and more aggressive fractionation schedules.

Educational Objectives:
1. Commissioning and quality assurance of optically guided 3D ultrasound patient positioning systems.
2. The clinical use of optically guided 3D ultrasound patient positioning systems.

MO-E-J-6B-02

Volumetric Image-Guidance for Therapy: Performance, Quality and Opportunity

D Jaffray*, Princess Margaret Hospital, Toronto, ON, CA

The recent developments in the field of imaging technology for specialized applications opens new and exciting frontiers for therapy guidance. In the context of radiation therapy, there is a growing expectation of volumetric imaging in the context of therapy. This expectation is coming in numerous forms ranging from CT-on-rails to megavoltage and kilovoltage CT systems embedded in the treatment system with each of these offering unique features and capacities that will be evaluated in the near future as this technology makes it's way into the clinical setting. The merits of image-guidance are difficult to dispute and multi-faceted. Clinical experience with one such technology has provided insight into the dimensions over which this technology might have impact on the therapy of cancer patients. While these technologies have been justified on their potential to improve the performance (accuracy and precision) of the therapeutic intervention - offering reduced toxicity and increased probability of cure through dose escalation - it is clear that this is not the limit of their value. The near-term benefits may be in their capacity for increasing the quality with which we execute conventional therapy regimens. Alternatively, the capacity of these systems to identify opportunities to make refinements to the therapy as the dynamic nature of the disease and therapy process is exposed may be their greatest contribution. Overall, the new information provided by these systems will change the face of radiation therapy.

MO-E-J-6B-03

In Room Magnetic Resonance Imaging Guided Radiotherapy (MRIgRT)

J Lagendijk*[1], B Raaymakers[1], U van der Heide[1], J Overweg[2], K Brown[3], C Bakker[1], A Raaijmakers[1], M Vulpen[1], J Welleweerd[1], I Jürgenliemk-Schulz[1], (1) University Medical Center Utrecht, NL, (2)Philips Research Hamburg, DE, (3)Elekta Oncology Systems, Crawley, GB

Precise, soft-tissue based, on-line position verification and treatment monitoring is a prerequisite for image guided radiotherapy (IGRT). The system being developed is a 1.5 T MRI scanner integrated with a 6 MV radiotherapy accelerator. Basically, the design is a modified 1.5 T Philips Achieva MRI scanner with a small, single energy (6 MV) accelerator rotating around it.
The technical feasibility of simultaneous irradiation and MR imaging will be discussed. The magnetic interference between the MRI system and the linear accelerator has been solved by modifying the active shielding of the magnet, minimising the magnetic field at the components of the accelerator and completely nullifying the magnetic field at the location of the accelerator gun section. The MRI system is being homogenized and the radiation thickness has been minimised to allow beam transmission through the midplane of the closed bore MRI system. A special gradient coil set has been designed with a radiation window allowing a 24 cm field size in the caudal cranial direction for every gantry angle. The dose deposition kernel in the presence of a transverse magnetic field has been investigated. The kernel has been quantified and special effects like the electron return effect (ERE) around air cavities, have been investigated.
It is shown that integrating MRI functionality with a radiotherapy accelerator is technically feasible. Ultimately the system may be used for daily treatment optimisation by providing the imaging information for on-line treatment planning. On-line MRI may also provide treatment monitoring and treatment response assessment required for further biological optimisation.

MO-E-J-6B-04

Panel Discussion

W Tome*[1] , D Jaffray*[2], J Lagendijk*[3] , (1) University of Wisconsin, Madison, WI, (2) Princess Margaret Hospital, Toronto, ON, CA, (3) University Hospital Utrecht, Utrecht, NL

Therapy Continuing Education Course Room 6C

CE: Site Specific IMRT Planning - I

MO-E-T-6C-01

IMRT for Head and Neck Cancer

T Pawlicki*, Stanford Univ School of Medicine, Stanford, CA

Clinical physicists have gained considerable experience with IMRT treatment planning over the past several years. The details of IMRT planning can vary significantly from site to site. The purpose of this presentation is to discuss key issues in IMRT treatment planning for head and neck cancers. Our main focus will be on details related to the planning process such as, immbolization, imaging, treatment planning, and plan evaluation. 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. 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 in 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 of the 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. This step may take on a greater importance as kV imaging techniques become more prevalent in the treatment room. 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.

MO-E-T-6C-02

IMRT of the Central Nervous System

M Munley*, V Stieber, Wake Forest Univ School of Medicine, Winston-Salem, NC

Most of the clinical work with intensity modulated radiation therapy (IMRT) has focused on its use for the treatment of patients with prostate or head/neck cancers. However, IMRT for the central nervous system (CNS) is becoming more commonplace in the radiation oncology community. 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) since multiple critical structures are confined within the intracranial vault, one may reason that optimization of the dose distributions should allow 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. In these cases, IMRT allows non-uniform reduction of the treatment volume around these structures. The goals of this presentation are to provide an overview of the practice of IMRT for the CNS, to review the corresponding published data, and to discuss future directions of exploration for CNS IMRT.

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 the actual radiation treatments. A discussion of the steps to 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, a review of published data is recommended. The focus of the review should examine both technological and clinical outcome data. 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 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.

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Therapy Scientific Session Room 618
Brachytherapy Treatment Techniques

MO-E-T-618-01

An Integrated CT-Based Monte Carlo Dose-Evaluation System for Brachytherapy and Its Application to Permanent Prostate Implant Postprocedure Dosimetric Analysis

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Purpose: To develop a novel integrated CT-based Monte Carlo (MC) dose-evaluation system and use it to investigate the effect of tissue heterogeneities and interseed attenuation on brachytherapy dose distributions. **Method and Materials:** A MC photon-transport (MCPT) brachytherapy dose-calculation engine, PTRAN_CT, which uses x-ray CT to estimate tissue cross-sections, is developed based on PTRAN_CCG version 7.44. PTRAN_CT uses fast ray tracing that combines patient anatomy modeling via 3D voxel arrays with modeling of sources and applicators via a general combinatorial geometry code. A generalized phase-space source is used for further increasing efficiency. PTRAN_CT uses cross-section data derived from a single-energy CT image. PTRAN_CT was incorporated into an integrated system for performing postimplant dosimetric analysis of permanent prostate implants. A clinical implant consisting of 78 Model-6711 I-125 seeds was investigated to quantify interseed and tissue heterogeneity effects. Three scenarios were simulated a) comprehensive MC simulation including tissue heterogeneities and complete seed geometry b) complete seed geometry in homogeneous water and c) homogeneous water using 2D TG-43 source superposition. **Results:** Compared to case b), tissue heterogeneities (case a)) reduce doses by 5.8% on average in the target volume, after excluding artifacts from CT data. Interseed effects (case b) vs c)), reduce doses by 3% on average. The seed streaking artifact in CT data can affect MC result as large as 6%. The efficiency of PTRAN_CT relative to the predecessor code PTRAN_CCG is increased by factors of two and five, respectively, with and without enabling the phase-space option. In case b), PTRAN_CT yields the same dose distribution as benchmarked PTRAN_744. **Conclusion:** A novel post-implant dose evaluation system, based upon an accelerated CT-based Monte Carlo brachytherapy dose-calculation engine, has been developed and its accuracy and efficiency demonstrated. Preliminary results suggest that tissue heterogeneity effects can be incorporated into the clinical planning process.

MO-E-T-618-02

Dosimetry of a Thyroid Uptake Detected in Seed Migration Survey Following a Patient's Iodine-125 Prostate Implant and Measurements of Seed Leakages

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Purpose: To improve the quality of prostate brachytherapy. A case of thyroid uptake following an I-125 prostate implant was previously reported. The abstract presents the methods to estimate the dose to thyroid and data of source leakages measured for different iodine-125 seeds. **Method and Materials:** Seed migration survey is provided to the prostate brachytherapy patients as a quality control procedure. Different implant techniques were evaluated to minimize the seed migration. To estimate the thyroid uptake dose from a seed ruptured during implantation, I-125 source intentional leakage is measured in vitro. A seed is cut open and placed in saline solution. The concentration of I-125 in the solution is measured over a period of 2 months. A leakage curve is obtained. Using MIRD model, the dose to thyroid is calculated. The thyroid counts at different times are used to verify the thyroid uptake dose. **Results:** Seven of 11 vendors distributing I-125 seeds in North America provided I-125 seeds in our seed leakage investigation. The measured data shows that the leakage half-life of a seed varies from 12 days to infinite for different manufactured seeds.

Based on the leakage data and patient measurements, we conclude that one seed was leaking in our thyroid uptake case. The estimated dose to thyroid is 263 cGy. **Conclusion:** The elimination of seed migration has been achieved and so the improvement of the implant quality. Since more and more prostate cancer patients will be treated by brachytherapy, increased incidences of thyroid uptake are expected. The measured seed leakage data can be used in the estimation of dose to thyroid in case a seed leak is encountered. **Conflict of Interest:** The project was partially supported by a fund donated by Mr. Malvin Bank. There is no conflict of interest.

MO-E-T-618-03

Dynamic Intraoperative Prostate Brachytherapy Using 3D TRUS Guidance with Robotic Assistance

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Purpose: Develop a dynamic intraoperative prostate brachytherapy system, in which all phases of the procedure are performed in one session, including planning, monitoring of prostate changes, dynamic re-planning, optimal needle insertion including oblique trajectories and automatic seed localization in US images, to deal with variabilities in the current procedure. **Method and Materials:** The system consists of 3D TRUS imaging, a robot and software tools for prostate segmentation, intraoperative planning, oblique needle segmentation and tracking, seed segmentation, and 3D dose planning. The robot and 3D TRUS coordinate systems are unified with robot and image calibrations. In 3D TRUS images, the prostate is segmented using discrete dynamic contour method, and optimal implantation plan is performed by applying geometric optimization followed by simulated annealing. The robot can be controlled to guide the needle to target points in 3D TRUS images along oblique trajectories accurately and consistently. The inserted needles are segmented and tracked using grey-level change, and seed segmentation is performed using 3D line segment patterns. **Results:** Needle placement accuracy of the robot at "patient" skin was 0.15mm±0.06mm, and needle angulation error was 0.07°. Needle targeting accuracy was 0.79mm±0.32mm. The average difference between manual and the prostate segmentation algorithm of prostate boundaries was -0.20±0.28mm. In our needle tracking tests, errors in determining needle orientation were less than 2° in robot *yaw* and 0.7° in robot *pitch* orientations, for up to 20° needle insertion angles when the needle insertion distance was greater than 15mm. The true-positive rates for the seed segmentation algorithm in 3D TRUS images were 100% for agar and 93% for chicken phantoms. With optimal planning tools provided, 98% of prostate volume receives 80% of dose coverage. **Conclusion:** The result of this work provides a tool to achieve dynamic intraoperative prostate brachytherapy using 3D TRUS imaging and robotic assistance together with efficient segmentation software.

MO-E-T-618-04

Treatment Planning Approach for Elongated Linear Sources for Prostate Implants

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Purpose: Recently pseudo and true elongated linear brachytherapy sources have become available for prostate implants. These sources were designed to eliminate the problems associated with loose seed type implants such as seed migration and embolization. However, majority of the commercially available prostate treatment planning systems are not capable to perform dose calculations with the elongated linear source types. In this project an intermediate solution for prostate treatment planning with elongated linear sources has been introduced using commercially available treatment planning systems. **Method and Materials:** Two new models have been introduced for calculating dose distribution around linear sources greater than 1.0 cm in length. Dose distributions around elongated linear source were obtained either by super position of 0.5 cm or 1.0 cm long source segments using line (LSS) or point (PSS) source approximation in treatment planning systems. These models have been validated by calculating dose distribution around RadioCoil^{TM} sources using Prowess^{TM} and VariSeed^{TM} treatment planning systems and comparing the results with Monte Carlo Simulated data. Clinical application of these models for a multi source implant has been validated by treatment planning for a sample prostate patient. **Results:** Results of LSS and PSS models are found to be in good agreement with of Monte Carlo simulated data (within 4%) for the points within the active length of the source. Discrepancy is noted for the points out side the active length of the source and is under investigations. Moreover, ABS recommended parameters obtained with these models for a sample prostate patient are in good agreement to that of "seed" type implant using Pd^{103} Model 200. **Conclusion:** These results show that the new models can easily be adapted for dose calculations with commercially available treatment planning systems for elongated linear sources. These models provide an intermediate solution for the treatment planning with elongated sources.

MO-E-T-618-05

Monte Carlo Study of the Effect of the Tissue Composition On the Dosimetric Data Used for Low Energy Photons

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Purpose: Low energy photon isotopes like Iodine-125 or Palladium-103 are widely used for brachytherapy applications, as in the treatment of prostate, eye or very recently breast. The mean energy is approximately 30 keV for Iodine-125 and 20 keV for Palladium-103. In the vast majority of brachytherapy treatment planning the patient is still considered as an infinite water phantom. The real compositions of the tissues, the presence of heterogeneities or the real shape of the body are not taken into account. In this work we used Monte Carlo techniques to estimate the impact of those approximations on the calculations of the dose distributions in the patient. **Method and Materials:** The radial dose functions were calculated for IBt seeds using MCNP4C in different situations and in different materials including different body tissues whose compositions were taken from ICRU44[1]. For these calculations, MCNP4C default cross section library was modified to match EPDL97[2]. **Results:** The differences between radial dose functions calculated in muscle and in water can be as high as 15% at 5 cm for ^{103}Pd and 10% at 5 cm for ^{125}I. For breast tissue the comparison with water shows an underestimation of the radial function of up to 50% at 5 cm from a ^{103}Pd seed. The same calculations in lens tissue show on the contrary a good agreement with the radial dose function calculated in water. Moreover, due to photoelectric absorption, we show that the presence of even very limited amount of high Z elements as heterogeneities or as component of the tissue has an effect on the radial dose function and so on the dose distribution around the seeds. **Conclusion:** The real composition of the body tissues should not be neglected because of the large influence of high Z elements due to the high photoelectric cross section for low energy photons.

MO-E-T-618-06

Correcting LDR Spectroscopy for Fine Energy Resolution Applications

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Purpose: To use high purity Germanium spectrometry to measure output energy spectra of LDR brachytherapy seeds in order to provide better dosimetric information than what is currently available. Such spectral information can provide a platform for energy based dosimetry of LDR seeds as well as provide 'energy output' benchmarks for Monte Carlo simulation of these sources. **Method and Materials:** Low energy Germanium spectroscopy suffers from several inherent defects of the spectrum collection process. Peak energy broadening and generation of fluorescence escape peaks are two defects, both of which can complicate and contaminate measured spectra. A correction algorithm is presented to overcome these defects and reproduce the true energy spectra without detector produced artifacts and without a priori assumptions as to the internal LDR seed structures. Collection of output spectra from various LDR seeds was obtained using an n-type Germanium spectrometer. A detector response function matrix (8037 element square) was constructed via detailed MCNP Monte Carlo simulations to characterize the detection process from the detector's entrance window to particle termination, spanning interactions from 1352 keV down to 3.75 keV. The correction algorithm is based upon an iterative algorithm used in high- to moderate-energy physics, as detailed in the literature for Germanium spectroscopy. This modified algorithm in conjunction with the response matrix reconstructs the spectrum as it was prior to interaction with the detector. **Results:** Corrected results have shown excellent agreement with expected theoretical spectral outputs, and spectral peak resolutions of less than 0.5 keV have been achieved. High resolution output spectra have been catalogued for multiple seed designs. Spectral Air Kerma Strength

calculations, utilizing corrected spectra, agree with NIST traceable calibrated Air Kerma Strengths to within 3%. **Conclusion:** This technique allows corrections to be made to acquired spectra thus yielding data for high resolution applications of non-energy-integrated dosimetry of LDR seeds.

MO-E-T-618-07

Toward An Energy-Based Dosimetry

L A DeWerd*, K Stump, W Culberson, S Beach, University of Wisconsin, Madison, WI

Purpose: To present a methodology for energy-based dosimetry for brachytherapy sources **Method and Materials:** Methodology for brachytherapy dosimetry is based on TG 43 formulism. For low -dose rate low-energy brachytherapy sources, TG-43 involves a measurement of the air-kerma strength traceable to NIST using the Wide Angle Free Air Chamber (WAFAC). A Variable Aperture Free Air Chamber (VAFAC) has been constructed for making air-kerma rate measurements with various solid angles. Both instruments provide a determination of the air-kerma strength. In addition, spectra of these seeds can be measured both in air and liquid water by an intrinsic germanium spectrometer. We have also recently measured the total energy contained and emitted from various sources using a novel cryogenic calorimeter. This provides an absolute measurement of the power of the source. Each of these experimental processes is presented in other papers. This talk is an overview of how these measurements can be combined to yield an energy-based dosimetry process. These measurements provide a good basis for Monte Carlo calculations. The energy standard would be used for calculation of dose or by extension, energy deposited. However, with extension to energy-based dosimetry, a modification of treatment planning systems for a gradual shift from TG 43 formulism will be necessary. An energy-based dosimetric formulism involves knowing the contained energy or the total emitted energy of a brachytherapy source. A review of the present dosimetry with an extension to energy-based dosimetry will be presented for discussion. **Results:** It is shown that energy-based dosimetry is feasible. The experimental parameters necessary are presented and are being measured presently. The results are very promising. **Conclusion:** This dosimetry schema is feasible and may be the dosimetry of the future. Moreover, this methodology provides an efficient platform upon which to base Monte Carlo dosimetry calculations.

Therapy Scientific Session — Room 617

Monte Carlo Methods I

MO-E-T-617-01

Energy and Intensity Modulated Electron Radiation Therapy Using a Monte Carlo Optimization Procedure

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Purpose: This study investigates the potential benefit of energy- and intensity-modulated electron radiotherapy (MERT) for superficial treatments and the possible intensity modulation by means of a multileaf collimator (MLC). **Method and Materials:** Detailed Monte Carlo simulation is proposed for the pre- and post-optimization dose calculation for MERT treatment planning. We have used 1 x 1 cm^2 electron beamlets with different weights and energies that are optimized by an integrated inverse planner following the imposed constraints for the target and critical structures. A leaf sequencer proposes the necessary segments shaped by the MLC and then, in a second optimization, the segments are considered as new beamlets, called 'blocklets', by the inverse planner. Dose distributions for individual blocklets are simulated accurately by Monte Carlo taking into account the effect of bremsstrahlung leakage and MLC leaf scatter. The leaf sequencer provides the final RTP file to be read by the linac. MERT and mixed beam treatments for breast cancer have been planned following the two-step optimization criteria. **Results:** The dose volume histograms (DVH) show clear improvement in the dose distribution before and after the second-optimization. The monitor units for individual segments are adjusted to correct for the effect of leaf leakage and scatter. A photon MLC has negligible leakage but more leaf scatter compared to an electron-specific MLC. The lung and heart doses are always less than 20 Gy and the best dose homogeneity in the target results from the two-step optimization. **Conclusion:** An optimization procedure based on Monte Carlo has been developed to ensure accurate treatment planning and beam delivery with MERT. The Monte Carlo procedure is also useful in the investigation of the best collimation geometry by simulating existing photon MLCs and prototype electron-specific MLCs.

MO-E-T-617-02

Dosimetric Evaluation of Inverse Monte Carlo-Based Modulated Electron Beam Treatment Planning and Delivery Using a Few Leaf Electron Collimator

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Purpose: To investigate the potential of improving the treatment planning and delivery of treatment to superficially located tumors using energy modulated electron therapy (EMET) based on inverse techniques and Monte Carlo dose calculation algorithms. This study investigates the application of EMET using a few-leaf electron collimator (FLEC) in head & neck, sarcoma, and breast sites in comparison with three dimensional conventional radiation therapy (3D-CRT) and intensity modulated radiation therapy (IMRT) techniques. **Method and Materials:** Treatment planning was performed for a parotid case, a sarcoma case, and a breast case. Three Monte Carlo calculated plans were compared for each case: 3D-CRT, IMRT, and 3D-CRT in conjunction with EMET (EMET-CRT). For all patients, dose volume histograms (DVHs) were obtained for organs of interest. For each plan, homogeneity and conformity indices of dose distributions, sparing index (SPIN50/10) that quantifies the conformity of the low isodose lines, and the whole-body dose equivalent (WBDE) were analyzed. **Results:** Adding EMET delivered with the FLEC to 3D-CRT preserves target conformity and dose homogeneity and improves sparing of normal tissues. For the head & neck case the mean dose to the contralateral parotid and brain decreased relative to IMRT by 43% to 84%, and by 57% to 71%, respectively. Improved normal tissue sparing is also quantified as an increase in sparing index of 47% and 30% for the head & neck and the breast cases, respectively. The WBDE for EMET-CRT was reduced by up to 72% when compared with IMRT. **Conclusion:** EMET delivered with the FLEC could be a valuable addition to currently existing treatment techniques especially when applied to superficially located tumors that are inherently difficult to plan using IMRT. The addition of EMET systematically leads to a reduction in WBDE especially when compared with IMRT.

MO-E-T-617-03

Direct Voxel Tracking Method for Calculating Dose in Deforming Anatomy

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Purpose: Current deformable dose calculation methods rely on simple translations or interpolations ignoring radiation field perturbation effects by the deforming structures. The aim of this work is to develop a method for Monte Carlo dose calculations where the dose deposition in voxels is directly tracked as the anatomy deforms. **Method and Materials:** The DOSXYZnrc/EGSnrc user code was modified to track dose deposition in non-rectangular voxels obtained by applying deformation vectors from image registration software to the reference geometry. In the geometry checking subroutines each voxel is divided into 12 planes and the distance to the nearest boundary is determined. The deformation method was tested by comparing dose deposition in a deformed phantom with a static phantom with the same dimensions. Dose distributions were compared for both a rigid phantom in which only internal boundaries are deformed and a phantom whose outer dimensions were compressed. Dose deformations due to breathing motion were investigated with the use of a mathematical lung phantom for which displacements based on a measured breathing curve were applied to simulate motion of the diaphragm. **Results:** Dose distributions agreed within 1% for the simple rigid phantom. In the case of the compressed phantom the dose within the phantom agreed within 0.5%. In the mathematical breathing phantom dose differences of up to 16% were noted between the exhale phase and the accumulated dose over a 4 sec

breathing cycle. **Conclusion:** We have developed a method for calculating dose in deforming anatomy where voxel coordinates are directly tracked as the anatomy changes. The code was validated by consistency checks and can be used to verify the validity of simplified dose reconstruction procedures such as translation or interpolation. We plan to implement this method to recalculate patient treatment plans using 4D-CT data.

MO-E-T-617-04

An Efficient Adjoint Monte Carlo Method for Radiation Treatment Planning

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Purpose: Adjoint Monte Carlo methods were originally developed for optimizing nuclear reactor designs, but have recently shown to be useful in radiation treatment planning. This study evaluates the efficiency of the AMC method and addresses several issues on implementing it into the MCNP code for potential IMRT treatment planning. **Method and Materials:** We compare the difference between an adjoint and a forward Monte Carlo calculations for computing time and dose. By exploring a tally feature (FT card) of MCNP, we then describe a source sampling scheme for multiple ROIs of the patient body in a single adjoint simulation. Two methods are used in this study to speedup the Monte Carlo simulations, which includes a mesh tally speedup and a variant reduction technique (VRT) using importance functions from the adjoint Monte Carlo calculations. **Results and Discussions:** The doses calculated by the forward and the adjoint MC are in a good agreement within statistical uncertainties. After normalized to the same statistical uncertainties, the computing time of the forward run is about 9 times of that of the adjoint run, which clearly demonstrates the computing efficiency of an adjoint simulation over a forward run. We also successfully implemented a source sampling scheme for different ROIs in only one simulation. This facilitates future implementation of an automatic AMC-based radiation treatment planning system. The VRT reduces the forward MC calculation time by approximately 26.7% for the prostate case. The reduction for the urinary bladder and the rectum is 24.8% and 13.6%, respectively. **Conclusion:** The efficacy and efficiency of the AMC method in achieving optimized dose objective have been demonstrated. The potential for the AMC method to be useful in treatment planning of IMRT procedures is particularly attractive because the large number of beam parameters involved.

MO-E-T-617-05

IMRT Planning Based On Various Photon Dose Calculation Techniques at Inhomogeneous Media

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Purpose: An EGSnrc-based Monte Carlo dose calculation tool was established to optimize fluence levels of intensity-modulated treatment fields. It was used to benchmark dose distributions in inhomogeneous human regions optimized with a superposition as well as a standard pencil beam algorithm in order to quantify the applicability of the dose calculation engines even during the optimization process. **Method and Materials:** An EGSnrc-based Monte Carlo dose calculation tool and a previously implemented superposition dose engine were adapted to a derivative of the inverse planning tool KonRad in order to iteratively optimize fluence patterns. BEAMnrc was applied to simulate 6MV and 15MV Siemens Primus accelerators. The acquired phase space information was input to a newly generated two-source photon/electron beam model. Excellent congruence between Monte Carlo simulations and dose measurements was achieved for homogeneous and inhomogeneous phantoms. **Results:** Using Monte Carlo as benchmark, the systematic and convergence error of a pencil beam and the superposition dose engine for five IMRT treatments of clinical lung and five head&neck cases were ascertained. The pencil beam overestimated the prescribed PTV dose up to 16.7%, severe deficiencies were even detected in respect to the convergence error. For the head&neck cases a significant overestimation of dose deposited at tumor-air-intersections was observed. The superposition algorithm mostly generates acceptable results apart from intricate lung cases, where the dose still was overestimated by up to 6%. **Conclusion:** Applying highly-sophisticated dose engines as superposition or Monte Carlo yields reliable dose information for IMRT-planning in target regions with intricate tissue inhomogeneities. Our studies showed, that in such regions superposition or Monte Carlo techniques have to be used for the optimization and the final dose calculation of intensity-modulated treatment plans, since standard pencil beam algorithms both lead to inappropriate fluence levels during the optimization and wrongly calculate the dose.

MO-E-T-617-06

Influence of Ion Chamber Response On In-Air Profile Measurements in Megavoltage Photon Beams

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Purpose: To investigate the influence of the ion chamber response including build-up cap materials, on the measurements of in-air off-axis ratio (OAR) profiles in megavoltage photon beams using Monte Carlo (MC) stimulations with the EGSnrc system. **Method and Materials:** Two new techniques were developed for the calculations of OARs when the ion chamber is oriented horizontally or vertically. For a horizontally oriented chamber pre-calculated tables of the response of an ion chamber inserted in a build-up cap for different photon energies was used to compute the dose deposited in the air cavity on-the-fly within the BEAMnrc simulation. For a vertically oriented chamber the BEAMnrc code was modified so that it can be compiled into a shared library that serves as a particle source for the CAVRZnrc user code. With these BEAMnrc and CAVRZnrc changes the OAR could be calculated on the fly without intermediate phase-space file generation. Results of the simulations were compared with experimental profiles from the 6, 10 25 MV photon beams from an Elekta Precise linac. **Results**: The calculated and measured in-air profiles for all investigated beams and build-up caps (brass, hevimet and two PMMA miniphantoms) are in a good agreement within the statistical and experimental uncertainties. The comparison between the calculated air-kerma and OAR profiles shows 3-6% differences between air-kerma and in-air profiles measured with hevimet and brass caps and 0.5-1% differences for measurements with PMMA mini-phantoms. **Conclusion:** The change of chamber response with distance from the central axis must be taken into account. For in-air profiles measurements PMMA mini-phantoms should be recommended over high-Z material build-up caps.

MO-E-T-617-07

Simulation of Organ Specific Secondary Neutron Dose in Proton Beam Treatments

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Purpose: To determine the effective secondary neutron dose to patients undergoing proton therapy. Goal was to separate the secondary radiation generated from the proton treatment nozzle from the one generated inside the patient. Further, the secondary dose should be calculated for specific organs independently. **Method and Materials:** GEANT4 based Monte Carlo methods were used to study the neutron induced secondary dose deposited to healthy organs/tissues during proton therapy. A whole-body patient model, VIP-Man, was implemented as patient model. Two proton treatment plans for tumor in the lung tumor and paranasal sinus were applied to VIP-Man. Internal (generated inside the patient body) and external (generated in the treatment nozzle) neutrons were studied separately. The averaged absorbed dose and neutron quality factor were deduced for each organ. The ICRP-60 tissue weighting factors were used to calculate the whole body effective dose. **Results:** The magnitude of secondary dose in organs/tissues depends on the distance to the primarily irradiated volume. In general, the averaged secondary dose is at least three orders of magnitudes lower than the planned dose in GTV. The neutron quality factor is calculated as to be ~6 since the neutron fluence includes a large fraction of thermal and low energy neutrons. Neutrons are mainly generated in the treatment nozzle. Results show that the whole body effective dose for the two proton plans is 0.162 Sv and 0.027 Sv, respectively. The statistic error of the estimated effective dose is better than 0.5% and 2% for internal and external neutrons, respectively. **Conclusion:** Our VIP-Man Monte Carlo method is an effective tool for secondary dose calculations in patient geometry. Secondary dose can be calculated organ specific. Our method can be used for any treatment

modality and is planned to serve as basis for more quantitative evaluation of secondary cancer risk following radiation therapy.

Therapy Symposium Room 6E
Biological Parameters in Optimization

MO-E-T-6E-01

Outcome Prediction Models in Radiotherapy: Methods for Improvement and Future Uses

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Historically, the ability to predict a patient's outcome to a course of radiation therapy has been very limited. Knowledge of a patient's likely response to a given therapy was quantified by the maximum slope of the sigmoidally-shaped patient population dose response curve: steep slopes correspond to precisely known individual dose thresholds, whereas shallow slopes correspond to poorly quantified individual dose thresholds. In the 3-D treatment planning era, the situation has been fundamentally altered: it is no longer adequate to characterize dose distributions by a single number, as the effect of any distribution, especially on normal tissues which are often non-uniformly irradiated, may depend in a complex way on the spatial distribution. It has been recognized for more than 60 years that irradiated organ volume can dramatically affect response. Efforts to quantify the 'volume-effect' began in earnest in the late 1980's, but have recently gained much more momentum and effectiveness due to the advent of 3-D treatment planning. In most investigations to date, the dose-volume histograms of irradiated organs or tissue structures are analyzed to determine the dose parameters which most correlate with outcome. Remarkably, most organ responses appear to fall (very roughly) into just two categories: in Group I, complication risks rise according to the volume given a dose above a relatively high-dose threshold (typically 50-60 Gy). These organs include the spinal cord, brain stem esophagus, rectum, and small bowel. In this group, organ function is related to organ structure. In Group II, complication risk is correlated with the mean dose or something similar; functional ability is partially impaired even at relatively low doses. This response group includes parotid glands, brain, liver, and lung. Simplified dose-response models were developed by Kutcher, Burman, Brahme, Niemierko and others which reflected this range of response behavior. However, those analyses are far from utilizing the full potential of image-based 3-D treatment planning, based as they are only on cumulative dose-volume-histogram (DVH) data. Moreover, they ignore other potential clinical risk factors, such as diabetes, age, etc. In this talk we will estimate the trajectory of evolving dose-volume-outcomes models, including the need to search for potential variations in functional sensitivity vs. anatomical location, the inclusion of patient and disease risk factors, the need for advanced modeling techniques, and the future use of other biomarkers (imaging or gene analysis-based) in combined models. Methods to deal with the crucial need to accelerate inter-institutional data collection, modeling, and public archiving will be discussed. Lastly, we will discuss the inevitable move towards treatment planning based on outcomes models (e.g., maximizing the probability of tumor control with acceptable complication risks), and how we can get there from here.

MO-E-T-6E-02

Dose-Volume Modeling & Clinical Radiotherapy: The Art of Systematic Oversimplification

SM Bentzen*, University of Wisconsin Medical School, Madison, WI

Science has been called "the art of systematic oversimplification" (Popper). Using this as a criterion, dose-volume modeling is a very scientific discipline! A flurry of more or less mechanistic models has been proposed but despite their conceptual appeal these models are obviously oversimplified representations of what we know about the radiation pathogenesis of side-effects of radiotherapy. From an empirical point of view, most clinical data sets do not provide sufficient structural resolution to allow validation of – or even discrimination between - any of these. Perhaps it is symptomatic that the most widely used, and in some sense most successful, dose-volume model is the "post-modern" model proposed by Lyman 20 years ago. Notwithstanding these philosophical concerns, dose-volume modeling has established itself as an exciting research field and a very useful tool in this age of conformal and intensity-modulated radiotherapy. Arguably, the use of these oversimplified models has greatly expanded and intensified the systematic collection and analysis of dose-volume data. It is tempting to draw a parallel to the use of the linear-quadratic model: originally this was closely linked to the target-cell hypothesis, a point of view that has all but disappeared now, where most researchers see the model as a pragmatic means of condensing empirical clinical data. Dose-volume models are currently used at two levels: to obtain a figure of merit for rival radiotherapy plans in daily routine planning and in the development of novel radiotherapy protocols to be tested in clinical trials. While current models have some credibility in the former application, they fail miserably in producing reliable, portable estimates of the absolute incidence of complications when applied in independent data sets or when extrapolated to considerably different dose distributions. This is not entirely the fault of the models: reliable estimates of the incidence of normal-tissue effects after radiotherapy are generally not available even in case of a uniform dose-distribution delivered to a critical structure. In the presentation, I will discuss dose-volume models from the perspective of evidence based medicine. How can these models be used in clinical trials design? And what are the most promising directions for future research? The possible effect of low-dose hyper-radiosensitivity and the challenge of incorporating the effect of cytotoxic drugs into dose-volume models will be discussed.

Educational Objectives:
1. To understand the strengths and weaknesses of current dose-volume models from the perspective of evidence based medicine.
2. To identify directions for future research on the clinical application of dose-volume models

MO-E-T-6E-03

Dose-Volume Modeling of Treatment Outcome

A Jackson*, Mem Sloan-Kettering Cancer Ctr, New York, NY

Since the landmark compilation of estimates of normal tissue partial volume tolerance doses and LKB model parameters by Emami et al. [1] and Burman et al. [2] in 1991, phase I dose escalation studies utilizing 3D conformal and IMRT techniques carried out in the last 10-15 years have provided quantitative data on dose volume dependencies of complication probabilities. For some organs the use of local and global function tests have provided data from objective endpoints which have been used to assess functional damage arising from irradiation of normal tissue. In concert with these developments, more rigorous statistical methods of model fitting and data analysis have been adopted. Improvements in our understanding of the dependence of complication probabilities on partial volumes of normal tissues irradiated will be described, including models for lung, liver, parotid, and rectal complications. Recent data from studies of radiation pneumonitis, including data suggesting variation in sensitivity of upper versus lower lung will be presented. Several limitations of current clinical data will be discussed: numbers for severe complications in single institution trials are usually small, and surrogate (lower priority) endpoints are often used, these have higher incidence and allow modeling with greater confidence, but are of less clinical relevance; use of fixed treatment techniques leads to correlations in values of dose-volume variables in the patient population, making discrimination between models difficult; effects of organ motion are difficult to remove post-facto and methods for accounting for them in outcome data in their infancy. To overcome poor statistics, merging of data from different institutions will be required. The difficulties of carrying out this task will be outlined.

[1] Emami B., et al., Tolerance of normal tissue to therapeutic irradiation. I.J.R.O.B.P. 21:109-122, 1991.
[2] Burman C., et al., Fitting normal tissue tolerance data to an analytic function. I.J.R.O.B.P. 21:123-135, 1991.

Educational Objectives:
1. To understand the advances made in our knowledge of dose-volume dependencies of normal tissue complication probabilities (NTCP) in the past 10-15 years.
2. To understand the limitations of our current knowledge of NTCP, and future work necessary to overcome these limitations.

Workshop Room 608

Display Evaluation Demonstration Workshop

MO-E-W-608-01

Display Evaluation Demonstration Workshop

E Samei*, Duke Univ, Durham, NC

The AAPM TG18 is a new initiative aimed to provide standard guidelines and procedures for acceptance testing and quality control of electronic display devices for medical applications. The recommendations, based on the newly-designed TG18 test patterns, include detailed visual and quantitative methods and specific acceptance criteria for objective assessment of display quality using the TG18 standard test patterns and specified equipment. The display characteristics considered include luminance, luminance spatial and angular response, resolution, noise, veiling glare, reflection, color uniformity, geometrical distortions, and display artifacts. The goal of this demonstration workshop is to present a tutorial and demonstration on practical aspects of display set up and display performance evaluation based on the TG18 methodology. Representatives from the TG18 committee and from industry will be present to demonstrate and discuss display evaluation issues.

Participants:
Jeffrey Charette, Barcoview, LLC
Ehsan Samei, Duke University Medical Center
Noriyuki Hashimoto, Eizo Nanao Corporation
Dave Sorensen, Image Systems Corporation
Kenneth Compton, National Display Systems
Adi Abileah, Planar Systems
Hans Roehrig, University of Arizon

TUESDAY, JULY 26

Imaging Continuing Education Course Room 618
CE: Breast Imaging Physics and Technology - II

TU-A-I-618-01
Evaluating Digital Mammography Systems
E Berns*, Northwestern University Feinberg School of Medicine, Chicago, IL

This lecture is going to discuss the relevant practical issues for the medical physicist who plans on performing physics testing on full-field digital mammography units. The lecture will be broken into parts. The first will discuss what is important in preparing for the testing that includes training recommendations, recommended and required test tools, and practical site issues. The second part will discuss important issues when performing the actual physics testing. This will include describing the actual physics tests and comparing them to screen-film mammography, measuring patient dose, evaluating for artifacts, evaluating clinical images, and experiences from previous testing. Finally, the third part will discuss the writing of the report, technologist QC, tips for dealing with the site, the techs, and the ACR. Relevant information and examples from the different FFDM unit manufacturers will be included throughout the lecture.

Imaging Continuing Education Course Room 617
CE: PET Physics and Technology - II

TU-A-I-617-01
Positron Emission Tomography Data Corrections and Calibrations
CS Levin*, Stanford University School of Medicine, Stanford, CA

There are several undesired physical effects inherent to the process of detecting annihilation photons in PET. These factors include photon attenuation, detector response non-uniformity, detector saturation, random and scatter coincidence background, and isotope decay. Acquired PET data must be corrected for these physical factors either before or during image reconstruction in order to facilitate qualitative and quantitative accuracy. Quantitative accuracy of PET image data further relies upon factors such as proper calibration to true isotope activity and correction for resolution blurring. We will give an overview of undesired physical factors affecting PET data and methods used to reduce or remove their effects through measurements and software algorithms. We will focus only on those techniques implemented in the current state-of-the-art commercial PET systems.

Educational Objectives:
1. To become familiar with physical effects that degrade the accuracy of PET data.
2. To understand common approaches taken to reduce or remove these unwanted effects.

TU-A-I-617-02
PET Scanner Performance: Quality Assurance and Acceptance Testing
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. Briefly, the crystal map converts the analog position of the detected event to a specific crystal within the block detector, while the coincidence timing calibration adjusts for timing delays so events from each block are time stamped equivalently. These characterizations are applied to the PET data during acquisition.

Daily quality assurance should determine whether the scanner is suitable for clinical use. A uniform cylinder of activity or rod sources are a good source of quality control data. These scans can be used to monitor system stability and to determine which crystals, blocks and modules (buckets) are more (or less) sensitive than the respective system average.

The NEMA PET NU2-2001 standard should be followed for acceptance testing. This standard uses a polyethylene phantom of 700mm axial length with a 3.2 mm line source to measure scatter fraction, count losses and randoms. This phantom approximates the out-of-field activity distributions of whole body scans. 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 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.

Imaging Continuing Education Course Room 609
CE: Digital Imaging Systems, Processing, Analysis and Display - II

TU-A-I-609-01
Characteristics and Performance Evaluation of Digital Image Displays
H Roehrig*, University of Arizona, Tucson, AZ

The diagnostic radiology department is in the middle of a revolutionary change [1, 2]. Digital imaging sensors and displays are replacing the traditional sensor and display, namely, the film-screen combination. In many institutions the Totally Digital and Film less Radiology Department already exists. Here images are generated using digital detectors, and diagnosis is made using softcopy displays such as Cathode Ray Tube displays (CRT) and Liquid Crystal Displays (LCD).

CRTs are analog devices while LCDs are discrete and digital devices. This presentation describes the resulting image quality in terms of spatial resolution or Modulation Transfer Function (MTF) and in terms of spatial and temporal noise or Noise-Power-Spectrum (NPS) and Signal-to-Noise-Ratio (SNR).

Basic display image quality affects greatly the presentation of clinical images on the specific display. It is the display, which determines if the image quality captured by the image detector is transferred to the observer, i.e. the radiologist. So the display has a special importance amongst all components of the imaging chain.

There is a need to test the image quality of the digital displays, called Acceptance Testing, when the displays are acquired from the display companies. In fact, before the acquisition of the displays by the user, there is a need for the display manufacturer to test the image quality of the digital displays in order to get FDA approval (i.e. 410 k). Amongst other performance characteristics the FDA wants to see the MTF and the NPS of the respective displays at several luminance values.

There is a need for Image Quality Control in the Reading Room, because many things can go wrong in the Reading Room: (1) The luminance of the digital displays (CRTs as well as LCDs) can change, (2) the spatial resolution of CRTs can change as the luminance changes because the MTF is related to the luminance through the size of the scanning electron beam, (3) the display can be set-up incorrectly. These problems need to be evaluated in the Reading Room.

The AAPM Task Group 18 has prepared a thorough report on "Assessment of Display Performance for Medical Imaging Systems".

•There are visual or qualitative or basic tests, where a human observer views the display and makes a decision on the presence or absence of a test object.

•There are quantitative or advanced tests, where an instrument like a photometer or a CCD camera is used to make a measurement and provide quantitative data.

Educational Objectives:
1. Understand the operational characteristics of CRTs and LCDs
2. Understand the concept of display Image Quality Evaluation.
3. Understand the need for acceptance testing of display image quality.
4. Understand the need for Image Quality Evaluation in the Reading Room
5. Understand the idea of the AAPM TG18 Assessment of Display Performance for Medical Imaging Systems
6. Understand the idea of quantitative evaluation of display image quality using a hand-held CCD camera.

Imaging Continuing Education Course Room 611
CE: Computed Tomography Physics and Technology - II

TU-A-I-611-01
Effect of Scan Parameters in Cardiac Imaging with MDCT
M Mahesh*, Johns Hopkins University School of Medicine, Baltimore, MD

Cardiac imaging has become a reality with the introduction of multiple-row detector computed tomography (MDCT) technology. Rapid evolutions in multiple row detectors ranging from 4 to 64 rows have led to the progression towards isotropic resolution imaging. This has become possible with improved technical factors such as sub-millimeter spatial resolution in z-direction (< 1mm), shorter scan time (< 400 ms), high temporal resolution (< 250 ms) and fast reconstruction of multiple data sets at various intervals in the cardiac cycle yielding larger 3D image data sets.

Recently CT imaging, especially cardiac imaging is not confined only to conventional imaging areas such as Radiology but is also performed outside the conventional imaging areas such as Cardiology. In such cases, medical physicists often become the conduit between imaging and non-imaging areas in assisting the clinicians to understand key features of MDCT. Therefore, it is critical for the medical physicists to become familiar with the various scan parameters and how they influence the overall image quality, so that he or she can provide valuable contributions towards developing appropriate scan protocols, developing strategies for radiation dose reductions and many other aspects.

CT image quality in general is influenced by a variety of scan parameters such as kVp, mAs, pitch, image noise, slice thickness, reconstruction algorithms etc. With cardiac CT imaging in mind, the presentation will discuss the effect of various scan parameters and how it affects the radiation dose and image quality.

Educational Objectives:
1. To become familiar with the advantages and disadvantages of various MDCT data acquisition modes.
2. To describe the effects of scan parameters on image quality and patient radiation dose.
3. To become familiar with spatial, temporal resolution and other key requirements in cardiac imaging.
4. To illustrate the image quality requirements in select clinical imaging sequences.

Therapy Continuing Education Course Room 6E
CE: QA for IMRT - II

TU-A-T-6E-01
Patient QA
C Ramsey*, S Mahan, Thompson Cancer Survival Center, Knoxville, TN

The number of patients treated with Intensity Modulated Radiation Therapy (IMRT) has grown dramatically over the past five years. Recent clinical studies have shown that IMRT has the potential to improve outcomes for multiple disease sites and pathologies. However, the clinical successful or failure of each individual institution's IMRT 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 for errors that can arise during IMRT planning and delivery, but it is ultimately the responsibility of the Medical Physicist to ensure that the Planned Dose "agrees" with the Delivered Dose. Unlike conventional and 3D conformal radiotherapy, IMRT plans must be verified for each individual patient because of the many sources of potential error. 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 Mechanics, and 3.) Time-Dependant Target/Tissue Positioning. The only method for determining the cumulative effect of all these potential sources of error is to measure the entire delivery sequence on the linear accelerator for each patient. Patient-Specific IMRT quality assurance (*QA*) measurements can be classified into three levels. Level I measurements are taken using film, diode arrays, electronic imaging devices, etc. The measurement device(s) are typically placed at depth in water-equivalent material. Level II measurements are taken with a phantom that moves to simulate intra-fraction motion (*such as respiration motion*). These measurements are typically made with film, diodes, and/or ionization chambers. Level III measurements are performed using daily CT imaging acquired on the delivery system (*CT-on-Rails, Cone-Beam CT, Megavoltage CT, etc…)*. Electronic detector data acquired during treatment delivery is then combined with the daily CT images to reconstruct the doses delivered to the patient. This presentation will discuss commercially available dose measurement tools, phantoms, and techniques for performing Level I and II patient-specific IMRT quality assurance. The current status of research and development in Level III IMRT quality assurance will also be discussed. Issues associate each technique will be discussed and clarified with practical examples. Recommendations will be presented for acceptable tolerances and testing frequencies.

Educational Objectives:
1. To understand the issues surrounding patient-specific IMRT quality assurance
2. To understand the difference between patient-specific QA techniques
3. To identify potential sources of errors in IMRT quality assurance
4. To understand the impact of target localization and patient positioning on IMRT

Therapy Continuing Education Course Room 6C
CE: TG-70

TU-A-T-6C-01
TG-70: Clinical Electron Beam Dosimetry: Supplement to TG-25
B Gerbi*, Univ Minnesota, Minneapolis, MN

Purpose: The purpose of this talk is to describe the intent and content of Task Group 70: Clinical electron beam dosimetry: supplement to TG-25.

Task Group 70 of the AAPM was formed originally to address the issues of clinical electron beam dosimetry in light of the changes brought about by the new calibration protocol TG 51. The latter task group gives a clear description of the procedure required to establish the dose rate at one point in a radiation beam. However, clinical dosimetry demands the ability to find the dose rate at any point in a radiation treatments field. TG 70 addresses these issues for electron beam treatments. Originally, Task Group 25 addressed these issues at the introduction of calibration protocol, TG 21 and provided direction for all aspects of clinical electron beam application in radiation therapy. Its initial intent was to give recommendations to practicing medical physicists, techniques for them to follow, and reasons for the particular recommendations. Task Group 70 has the same intent as the original TG 25 but to do so in light of not only TG 51 but also to take into account advances in the field since the time of TG 25. Improvements in the accuracy of correction factors such as the incorporation of realistic stopping powers for electron beams, P_{wall}, P_{gr} and P_{fl} , are describe along with improvements in electron beam treatment planning or improvements in techniques that have taken place since the original TG25 report. Each section states clearly the reason for that particular section, the problems that are addressed, or the new information that has been developed since TG 25. The solutions to those problems, the

actions needed to be taken by practicing clinical medical physicist, and other direction is provided in each section.

Practical clinical aspects of electron beam dosimetry will be discussed including techniques for determining the output factors, percentage depth dose, and output factors and central axis percentage depth dose measurements for small, irregularly shaped electron beams. The final section of the task group report describes clinical applications of electron beams.

Therapy Continuing Education Course Room 6B
CE: Regulatory Update for Brachytherapy

TU-A-T-6B-01
Regulatory Update for Brachytherapy

G Glasgow*, Loyola Univ Medical Center, Maywood, IL

In the past ten years significant changes occurred in brachytherapy and its governing regulations. The professor reviews the use of the world-wide-web Internet to disseminate regulations, discusses changes in types of brachytherapy procedures, considers concerns about by-product material security, and reviews recent federal codes and their implementation by agreement states. Current web addresses are presented for international organizations that make recommendations that become the basis of subsequent federal regulations made by federal agencies. National trends (increases in "seed" implants and HDR treatments; declines in traditional gynecological treatments and intravascular use, etc.) in brachytherapy are reviewed. Do you know where your sources are*? Who else knows?* Security of byproduct sources, small multiple millicurie quantities of long-lived byproduct materials (^{137}Cs, ^{60}Co, etc.), in medical facilities is a new international and national concern that will likely will lead to new national and state regulations requiring greater security for radioactive sources. Unchanged regulations, *10 CFR 19 (Notices, Instructions, and Reports to Workers; Inspections), 10 CFR20 (Standards for Protection Against Radiation)* are reviewed, as well as changes in *10 CFR20 (Standards for Protection Against Radiation), 10CFR32 (Specific… Material)*. As time permits, 126 sections of *10CFR35* (*Medical Use of Byproduct Material)* applicable to all forms of forms of radiation, manual brachytherapy, and photon-emitting remote afterloaders are discussed. If you haven't read the "new" (4-24-02) USNRC 10 CFR 20, 32 and 35 Regulations, this limited presentation (NB: "Regulations Lite") reviews the cogent details of regulations that did not change as well as those that did. Authorized Medical Physicist (AMP), and the training thereof, is defined, as well as types (LDR, PDR, HDR) of remote afterloading units (RAU), including medium dose rate (MDR) and mobile services. Roles of management, the radiation safety officer (RSO), and authorized users (AU) supervision of individuals are explained. Dose prescriptions, or written directives (WD) details and procedures are enumerated. Source inventories are now at 6-month intervals; there are new release criteria for patients as well as rules for decay-in-storage of RAM. Record retention and medical events reporting requirements are explained. Bulletins, Directives, Guidance's, Informational Notices, News Letters, and Regulatory Summaries for Brachytherapy are described, and recent NRC activities discussed. Understanding codes, regulations, and license conditions has to be the least exciting part of a medical physicist job! Federal codes are the basis for state codes, but state codes are not identical to federal codes, even in agreement states. Compliance with myriad regulations and license conditions is a challenge. By knowing the origin of codes and regulations an AMP can write a better license! So, if you are an AMP who wants to your AU to write a proper WD to avoid an ME on your RAU during HDR, attend this lecture! (If you don't understand this last sentence, you particularly need to attend!)

Imaging Continuing Education Course Room 618
CE: Radiographic and Fluoroscopy Physics and Technology - II

TU-B-I-618-01
A Comparison of Screen/Film and Digital Imaging: Image Processing, Image Quality, and Dose

R Schaetzing*, Agfa Corporation, Greenville, SC

By almost any measure, there have been dramatic changes in projection radiographic imaging technology in the 110 years since Roentgen's discovery of x-rays. We have come from hand-mixed, primitive photographic emulsions deposited onto glass plates to advanced flat-panel, digital detectors based on amorphous-silicon, thin-film transistor (TFT) arrays (deposited onto glass plates!). During this period, screen/film (S/F) imaging has developed to a high level of sophistication and image quality, and is still improving. Why then is there an inexorable movement away from analog, S/F technologies to digital imaging technologies? Do digital systems produce images with better inherent image quality than that of S/F systems? Does the ability to manipulate digital images lead to higher image quality or improved diagnostic performance? Can digital images really be made at reduced patient dose? Or, is the move to digital simply a matter of convenience or control? Why does it matter at all which technology is "under the hood" of an imaging system, as long as the clinical application works as intended? Some of the proclaimed advantages of modern digital systems, such as image processing, high image quality, and the ability to lower dose are, in fact, also available in S/F systems, but they are, at best, underutilized in a S/F-based clinical practice. The reasons for this have less to do with the imaging results than they do with the amount of effort required to achieve and maintain them. On the other hand, current experience suggests that these same digital advantages have yet to translate into real clinical advantages over existing imaging technologies. For example, while the image quality of radiographic imaging systems has changed dramatically over the years, the ability of radiologists to make an accurate diagnosis from the information presented in a radiograph has remained essentially unchanged over the time period that such measurements have been made (since the mid-1950s). If the radiologist is the performance-limiting step in the diagnostic imaging chain, perhaps it is pointless to continue to improve image acquisition technologies? On the other hand, new image processing techniques, such as computer-aided detection (CAD), have demonstrated that it is possible to improve radiologist performance with digital technology (ironically, the first widespread use of CAD, mammography, involves the digitization of S/F images). The low correlation between image quality and performance may also be explained by the radiologist's skill in "reading through" image quality variations to get to the relevant clinical information. By implication, manufacturers have yet to produce a significant enough image quality improvement to "move the needle" in diagnostic accuracy. This may be changing with recent developments such flat-panel, TFT arrays and computed radiography systems using structured-phosphor detectors. The bottom line: a rational comparison between S/F and digital systems involves more than a simple comparison of technical specifications.

Educational Objectives:
1. Describe the technical capabilities and limitations of screen/film technology relative to selected digital imaging technologies
2. Put into clinical perspective the promised advantages of digital imaging systems

Conflict of Interest: the author is employed by Agfa Corporation

TU-B-I-618-02
Converting the Radiology Department From Film-Screen to Digital – Making the Transition

S J Shepard*, U. T. M. D. Anderson Cancer Center, Houston, TX

In recent years, Picture Archiving and Communications Systems have begun to proliferate in the medical community. This is a result of technical advances that have occurred in two areas - advances in computer technology (such as storage density, processing speeds, network bandwidth, compression techniques, and so on), and the maturation of robust standards for communication and transmission of medical images and information (Standards like HL-7, DICOM, and IHE). In parallel with these developments, the medical imaging equipment and information systems vendors have been developing robust software implementations and more advanced system architecture to take advantage of this emerging technology and these robust standards. As a result of this revolutionary change in the way we operate, it has become increasingly important that we in the Medical Physics community modify our approach to the type of support we bring to these operations accordingly.
This presentation will focus on some of the issues the Medical Physicist is likely to face when supporting a clinical operation that is undergoing (or is

about to undergo) a conversion from film-screen base radiography to digitally acquired images. It will cover the educational needs of the Medical Physicist, radiologists and technical staff, how to use photostimulable phosphor imaging to introduce a radiology department to digital imaging, the importance of Modality Work List Management in the filmless radiology environment, selection of a DDR system for clinical use, weaning the referring clinicians off of film and what issues are important to achieving this, quality control programs for digital imaging systems, and finally those features of the radiology reading room environment that are important for soft-copy interpretation.

Imaging Continuing Education Course Room 617
CE: Magnetic Resonance Imaging Physics and Technology - II

TU-B-I-617-01
High Field MRI - Technology, Applications, Safety, and Limitations
RJ Stafford*, UT M.D. Anderson Cancer Center, Houston, TX

Signal-to-noise ratio in conventional magnetic resonance imaging (MRI) is inextricably tied to the static magnetic field strength (B_0). Until recently, most clinical MRI scanners operated at field strengths at or below 1.5 Tesla. However, due to technological advancements in magnet design and shielding, which ease siting requirements, 3 Tesla clinical scanners are now enjoying wide commercial availability and there is a push for even higher field whole body scanners (7-9Tesla) throughout the industry.

The drive towards high-field MRI is fueled by the benefits of potentially higher signal-to-noise ratios, contrast-to-noise ratios, and spectral resolution. In many cases, these benefits translate directly into higher spatial and/or temporal resolution than previously possible with MRI at lower fields as well as the ability to explore new territory, such as molecular imaging. There are, however, very real technological, physical and safety limitations that must be navigated and may limit the full realization of these benefits at high-field. Technology issues include homogeneity of the static and radiofrequency magnetic fields, higher gradient coil performance and linearity, and the design of robust radiofrequency array coils for signal reception. At high-field, physics concerns include changes in relaxation kinetics, increased susceptibility effects and other changes in contrast mechanisms. Safety limitations include higher power radiofrequency pulses and the potential for tissue heating or coil burns, stimulation effects from stronger, faster switching gradients and physiological effects of motion within the high-field environment and, most prominently, the potential dangers associated with the main magnetic field, such as ferromagnetic projectiles in the scan room and effects on implanted medical devices, many of which have yet to be evaluated at fields above 1.5 Tesla.

Ultimately, design of protocols and acquisition methods that account for these limitations need to be pursued in order to reap the benefits of high-field MRI without compromising patient safety. Many MR imaging techniques have already seen demonstrable improvement at higher fields and have driven the development and distribution of high-field systems. Techniques in functional magnetic resonance imaging relying on blood-oxygen level dependent contrast mechanisms, techniques in angiography and techniques in dynamic susceptibility contrast perfusion imaging all benefit from higher fields. Changes in relaxation kinetics can provide enhanced contrast for angiography and arterial spin labeling techniques. Additionally, proton MR spectroscopy methods for brain and body imaging benefit from the higher spectral resolution of high field as do multi-nuclear techniques.

This course will review the technology and physics behind the emerging high-field systems (3-9 Tesla) with emphasis on the commercially available and widespread 3 Tesla systems. Major applications of high-field MRI will be addressed with an eye on the future. Aspects of safety in high-field MRI will also be covered, paying particular attention to how safety considerations may influence the development and implementation of patient protocols at higher fields.

Educational Objectives:

1. Introduction to relevant high-field technology, physics and techniques.
2. Understand benefits and limitations of high-field MRI.
3. Understand safety concerns associated with high-field MRI systems.
4. Awareness of some of the most relevant applications of high-field MR imaging.

Imaging Continuing Education Course Room 609
CE: Ultrasound Imaging Physics and Technology - II

TU-B-I-609-01
Therapeutic Ultrasound
L Crum*, Center for Industrial and Medical Ultrasound, University of Washington, Seattle, WA

The use of ultrasound in medicine is now quite commonplace, especially with the recent introduction of small, portable and relatively inexpensive, hand-held diagnostic imaging devices. Moreover, ultrasound has expanded beyond the imaging realm, with methods and applications extending to novel therapeutic and surgical uses. These applications broadly include: Tissue ablation, acoustocautery, lipoplasty, site-specific and ultrasound mediated drug activity, extracorporeal lithotripsy, and the enhancement of natural physiological functions such as wound healing and tissue regeneration. A particularly attractive aspect of this technology is that diagnostic and therapeutic systems can be combined to produce totally non-invasive, image-guided therapy. This general lecture will review a number of these exciting new applications of ultrasound and address some of the basic scientific questions and future challenges in developing these methods and technologies for general use in our society. We shall particularly emphasize the use of High Intensity Focused Ultrasound (HIFU) in the treatment of benign and malignant tumors as well as the introduction of acoustic hemostasis, especially in organs which are difficult to treat using conventional medical and surgical techniques. [Supported in part by the NIH and the US Army]

Imaging Continuing Education Course Room 611
CE: Radiation Safety and Risk Management - II

TU-B-I-611-01
Releasing Nuclear Medicine Patients to the Public: Dose Computations and Discharge Instructions
R Reiman*, Duke Univ Medical Center, Durham, NC

Thousands of patients are treated annually in the United States with iodine-131 for various medical conditions. Prior to 1996, patients treated with more than 30 millicuries of iodine-131 were required to be hospitalized in a private room until their iodine-131 body burden decreased to less than 30 millicuries. In 1996, the United States Nuclear Regulatory Commission (NRC) introduced a revision to 10 CFR 35.75 that permitted release based upon the anticipated dose to members of the public, rather than upon patient body burden. Consequentially, many treatments that formerly required hospitalization may be performed as outpatient treatments, and required hospitalizations can be significantly shortened. These regulations have been adopted by the Agreement States, and "early release" of in-patients and treatment as outpatients is becoming more widespread. Medical physicists who work in hospital settings can expect to participate in "early release" and outpatient radioiodine therapeutic procedures. Medical conditions that are treated with iodine-131 include hyperthyroidism, thyroid cancer, neuroendocrine tumors and non-Hodgkin lymphoma. Candidacy for outpatient treatment depends in part upon whether patients are continent of urine and capable of self-care. The revised NRC regulations permit conservative public dose computations that account for tissue shielding, biological elimination, physical decay and occupancy factor, which is an index of the amount of time members of the public could spend in close proximity to the released patient. Computations must demonstrate that radiation dose to members of the public will not exceed 500 millirem (5.0 mSv) if the patient is to be released. If the patient is released based upon such computations, a record of the release must be created and retained by the licensee for three years. The record must document the anticipated dose to a member of the public

and the method by which the anticipated dose was calculated. In addition, detailed written instructions regarding how the patient can maintain the radiation dose to family members other members of the public as low as reasonably achievable (ALARA). The implementation of "early release" has apparently been successful from an ALARA standpoint. Measurements of actual external radiation exposure to family members of released iodine-131 patients demonstrate cumulative doses that are a small fraction of the anticipated dose computed using conservative assumptions.

Educational Objectives:
1. Introduce participants to the medical conditions that are treated with radioiodine.
2. Review the regulatory considerations under 10 CFR 35.75 and 10 CFR 20 regarding both inpatient and outpatient radioiodine procedures.
3. Review ways in which the regulatory requirements may be satisfied, including dose-rate measurement, "public" radiation dose computations, post-discharge instructions, and addressing the concerns of patients and their families. Web-based methods to facilitate documentation of outpatient treatment will be introduced.

Therapy Continuing Education Course Room 6E
CE: Optimization for IMRT - II

TU-B-T-6E-01
Advanced Topics in IMRT Treatment Planning
J Deasy*, Washington Univ, Saint Louis, MO

IMRT treatment planning is fundamentally different from previous methods of computerized radiotherapy treatment planning, because (1) the user is asked to initially specify characteristics of the desired solution, and (2) the treatment plan is computer-derived using multivariable optimization techniques. Hence, the method is sometimes called 'inverse treatment planning.' However, this process is typically hindered by the need to guess which parameters will lead to an acceptably good plan. Typically the 'right parameters' to lead to an acceptably good plan are unknowable and this fact leads to a series of iterations in which the human user refines the input data guesses given to the planning system. The difficulty is related to the common commercial use of linearly weighted sums of objective function terms. It is routine, therefore, for dose hot spots and cold spots to shift, even between different structures, in an uncontrolled manner. A related paradox of the typical planning process is that normal tissue weights in the objective function should be small (so as not to negatively impact target dose characteristics) but not too small (so that dose to the structure will be reduced). Finding this range, which may not exist to satisfaction, is a trial and error process. Another difficulty is that DVH-outcome data collected using one type of treatment planning (say, 3-D conformal) probably applies less well to dose distributions which minimize just those stated metrics (as done in IMRT treatment planning). Other sources of planning error include: the relationship between DVH dose target goals and their impact on outcome, doubts about which beams should be selected, and the impact of dose algorithm accuracy on optimized target coverage. This review course session will focus on advanced IMRT treatment planning topics, including: (1) the effect of dose calculation approximations on IMRT solution characteristics, (2) beam selection techniques, (3) methods to deal with uncontrolled tradeoffs between different dosimetric objectives (e.g., prostate DVH vs. rectal DVH), including *ad hoc* methods and emerging alternatives to standard optimization methods (such as prioritized optimization), (4) radiobiological input data (e.g., DVH constraints) relevant for prostate and head and neck planning, and (5) emerging planning techniques based on radiobiological outcomes models (e.g., EUD, TCP, and NTCP). *Ad hoc* methods to control tradeoffs in current systems include multi-step approaches in which the target is optimized first, followed by adding the next most important normal tissue structure while holding the target DVH as a constraint, followed by adding other normal tissue structures, and so on. These issues will be discussed in the context of current commercial systems as well as emerging approaches.

Educational Objectives:
1. Review of methods for selecting number and orientations of beams.
2. Discussion of the effect of simplified dose calculation algorithms on treatment plan quality.
3. Review of radiobiological data, including dose volume constraints, commonly used for IMRT planning of head and neck and prostate plans.
4. Discussion of practical, as well as emerging, methods to control dosimetric tradeoffs in IMRT planning.
5. Discussion of radiobiological optimization vs. dosimetric optimization.

Therapy Continuing Education Course Room 6C
CE: Imaging for Treatment Planning - II

TU-B-T-6C-01
MRI and MRSI in Radiation Therapy Treatment Planning
L Xing*, Stanford Univ School of Medicine, Stanford, CA

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 intensity modulated radiation therapy (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. Clinically, MRI imaging is an important anatomical imaging modality and posses superior soft tissue contrast. It has played a pivotal role in radiation oncology practice and made significant impact in cancer diagnosis, staging, treatment planning, and monitoring of therapeutic response. In the last decade, much progress has been made in high field MRI and in the development of new MRI contrast agents. MR spectroscopic imaging (MRSI) has also emerged as a powerful noninvasive tool for providing the type of metabolic and physiology information needed to identify biologically conformal dose distributions for biologically conformal radiation therapy (BCRT). This presentation will provide an overview of the fundamental principles of MRI and MRSI imaging and inform the audience with some of the new developments in the field and their practical implications to radiation therapy. Examples of these applications in a few disease sites will be presented. Finally, issues related to the quality assurance of MRI/MRSI and BCRT will also be addressed.

Educational Objectives:
1. Review MRI and MRSI physics.
2. Illustrate the steps involved in integrating MRI and MRSI into treatment planning process.
3. Introduce MRI/MRSI image fusion techniques (including deformable image registration).
4. Provide an overview on recent advances in high field MRI and MRSI.
5. Update on the new development of MRI contrast media, including nanoparticles-based contrast agents.

This work was supported in part by NCI 5R01 CA98523-01.

Therapy Continuing Education Course Room 6B
CE: Transition to Hetero Corrections

TU-B-T-6B-01
Transition to Heterogeneity Corrections
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With the publication of the AAPM's TG-65 report on inhomogeneity corrections for photon beams, physicians and physicists must clearly understand how implementation of such corrections impact dose prescriptions. The TG report details the physics of the heterogeneity algorithms, methods to evaluate these prescriptions, limitations, and most importantly, how to implement. The report gives clear recommendations as to the dialogue needed before implementation takes place. A clinic should perform simultaneous plans by planning and treating the patient with no corrections applied. A simultaneous plan is generated that applies the correction 'after the fact', thereby leaving the homogeneous (and therefore given doses) intact. This will educate the staff as how prescriptions may (or may not) be altered according to the differences observed. In addition, planning volume margins may be affected according the algorithms' ability

to calculate penumbra in the presence of inhomogeneous media, particularly lung. In addition, classic beam arrangements may need to be scrutinized due to the impact of increased exit dosing observed with corrections applied.

MDAH found that implementation of inhomogeneity corrections was fairly easy to accomplish, even in a busy clinic. Accounting for heterogeneity resulted in better PTV coverage by changing beam weighting, without significantly changing isocenter dose. The distance from PTV to block edge also increased in some situations. Failure to account for tissue heterogeneity could lead to dose calculation errors, particularly to the PTV, which often results in significant underdosing. Accounting for tissue heterogeneity using many commercially available algorithms changes the dose to the PTV much more than will the future use of Monte-Carlo-based dose calculation algorithms. Heterogeneity corrections are particularly important when using IMRT, particularly in lung cancer treatment. They concluded that the benefits of accounting for tissue inhomogeneity vastly outweigh the minor difficulties with its implementation, will result in more accurate calculation of dose distributions, and hopefully in better outcomes for patients. The use of heterogeneity corrections also allowed the use of higher energy photon beams in 3D planning, because of greater confidence in dose calculation accuracy.

This course will give direction along with caveats in applying inhomogeneity corrections from the perspective of physics and physicians. In addition, there will be a review of current algorithms commercially available, along with a historical perspective on how various stages of algorithms impacted the radiotherapy community on evaluating and using inhomogeneity corrections.

Educational Objectives: The physicist will learn -
1. the details of TG-65
2. details on commercially available algorithms including limitations
3. the MDAH approach to implementing corrections
4. a historical perspective of studies on evaluating corrections
5. TG-65's recommendation plan for a clinic's implementation.

Imaging Scientific Session Room 609
Image Science and Perception

TU-C-I-609-01
The Differences Method for the Tissue Structured Noise Determination in Digital Mammography

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Purpose: To propose a new method for the estimation of the tissue structured noise, based on the differences distributions among neighboring pixels. **Method and Materials:** Breast tissue structured noise (σ_T) is determined as the difference between the total and system noise. The system noise (σ_{SYS}), which includes quantum and apparatus noise, is determined using digital mammography images without an object. The total noise is obtained from the differences distributions among neighboring pixels in the region where the compressed breast thickness is constant. The range of raw pixel values is split into intervals to suppress the quantum noise variation contribution and σ_T is determined for each interval. 280 Senographe 2000D clinical images from 100 unselected patients were collected and analyzed. Also based on the differences distributions for a flat phantom, we propose a method to estimate spatial resolution for pixelized detectors. **Results:** The average measured value of σ_T / σ_{SYS} is 0.45±0.15 for the 10 cycles/mm frequency and for all the pixel value intervals. The absolute value of σ_T for the same frequency is estimated to be 1.7 ± 1.0 microns in microcalcification thickness equivalent. The σ_T is also determined down to 1 cycle/mm frequency. The estimated Senographe 2000D spatial resolution is approximately 60 microns. **Conclusion:** The proposed method for σ_T and resolution estimation is very simple and fast enough to use in online image processing, not requiring a complex signal/background analysis. The main limitation of the method for low frequencies (less than 1 cycle/mm) is statistical.

TU-C-I-609-02
Bandpass Observer Detection Mechanisms in Structured Noise

C Abbey*, M Eckstein, UC Santa Barbara, Santa Barbara, CA

Purpose: The use of medical images to detect and classify disease involves interpretation of images with spatially correlated variability. These variations can arise from physical processes in detection such as electronic and quantum noise, from patient to patient variability (often referred to as "patient structured" or "anatomical" noise), and from image processing algorithms such as image reconstruction and contrast enhancement. A number of linear observer models have been suggested as predictive of human observer performance for the purposes of optimizing imaging systems for diagnostic performance in noise limited tasks. We investigate some of these models in three simple detection tasks in Gaussian textures with lowpass, highpass, and uncorrelated (white) power spectra. **Method and Materials:** We use a recently developed methodology to directly estimate a linear observer template in two-alternative forced-choice (2AFC) detection tasks with white noise, lowpass noise, and highpass Gaussian noise. In all cases the signal to be detected was a small Gaussian "lesion". After training, three human observers participated in the studies which involved 2,000 2AFC trials per condition. **Results:** The observed linear templates exhibit a bandpass structure in all cases. The peak of the spatial frequency band used by observer's shifts under different correlation structures. Various models, including Hotelling, Channelized Hotelling, Nonprewhitening, and Eye-filtered Nonprewhiteing models were compared to the human observer data. **Conclusion:** Human observers adopt different visual strategies in response to the correlation structure of images that is reasonably well modeled as a bandpass filter. Many suggested models of detection performance do not fully capture this filter.

TU-C-I-609-03
Effects of Exposure and Structural Background On the Detection of Computer-Simulated Nodules in Digital Chest Phantom Images: 2-AFC Study

C Lai*, C Shaw, B Sabloff, T Wang, X Liu, L Chen, Y Meng, S Tu, M Altunbas, S Kappadath, Univ of Texas M. D. Anderson Cancer Center, Houston, TX

Purpose: To investigate how the exposure level and structural background affect the detection of computer-simulated nodules in digital chest phantom images. **Method and Materials:** Images of an anthropomorphic chest phantom were acquired with an a-Si/CsI flat-panel based digital radiography system at 120 kVp and a tube current ranging from 0.25 to 32 mAs. The source-to-image distance (SID) was increased and the x-ray beam filtered to further reduce the exposure levels. 1-cm diameter computer-simulated nodules with a contrast ratio of 2.68% were computer generated at various locations of the chest images. Two-alternate forced choice (2-AFC) experiments were performed to measure the ratio of correct observations as a function of the exposure level for various structural backgrounds present. For each exposure level and location, 30 pairs of 512x512 images were generated and displayed in pairs on a review workstation for reading. The ratio of correct observations versus exposure levels were computed from the reading scores for various locations. The plots along with the exposures corresponding to 90% accuracy were used to study the effects of structural backgrounds. **Results:** For all regions, the accuracy generally increases from 0.5 to 1.0 with the exposure. However, the threshold exposure for 90% accuracy varies with the location. In the abdomen region, the ratio of correct observations reaches 90% at a higher exposure level (~ 0.4 mAs). In the lung region, the ratio reaches 90% at a much lower exposure level (~ 0.0625 mAs). The difference in the threshold exposures may be due to the heavier attenuation in the abdomen region. Complexity of structural backgrounds may affect the threshold exposure and the level and consistency of the ratios measured.

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TU-C-I-609-04
Optimization of Radiographic Imaging Using Simulated Radiography and Electronic Observers

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Purpose: Software incorporating an anatomical radiograph simulator, effective dose calculator, and image quality analysis has been developed to

determine the optimal balance between patient dose and image quality. **Method and Materials:** Radiograph simulation is divided into the primary and scattered portions of an x-ray interaction. A tomographic phantom, VIP-Man, is used to simulate the scattered portion using the ESGnrc Monte Carlo code. The primary portion is simulated using the projection ray-tracing method through the Visible Human CT data set. To produce a realistic radiograph, the software simulates quantum noise, blurring effects, lesions, detector absorption efficiency, and other imaging artifacts. The primary and scattered portions of the simulated radiograph are combined to form an image for simulated observer studies and image quality analysis. Absorbed doses in the VIP-Man phantom were also obtained from the Monte Carlo simulations. Once radiographs are produced, they are analyzed using several simulated observer filters including; non-prewhitening matched filter with eye, Hotelling, and channelized Hotelling. Using the VIP-Man phantom as a representative patient, a CsI flat panel detector and a small lesion in the left lung was examined as a test case. Energy was varied mono-energetically while fluence was varied. Approximately 2000 simulated images and 200,000 data files were analyzed. **Results:** Receiver Operator Characteristic (ROC) curves and the corresponding Area Under Curve (AUC) charts were developed for the 2000 simulated images. For the patient size considered, the energy at which the minimum effective dose required to obtain an AUC of 0.85 was determined to be 70 keV. **Conclusion:** Coupling an imaging simulator with a computerized simulated observer represents a new avenue for maintaining image quality while minimizing patient dose. Rescaling the VIP-Man phantom will extend the database of representative patients for a verity of imaging tasks.

TU-C-I-609-05

Image Contrast and Lesion Detection in Chest Radiography

A Vance, W Huda, K Ogden*, E Scalzetti, M Roskopf, SUNY Upstate Medical University, Syracuse, NY

Purpose: To assess the affects of varying image display contrast on lesion detection in chest radiography. **Method and Materials:** We investigated the detection of simulated mass lesions in three anatomical regions of chest radiographs (apex, hilum, and sub-diaphragm). Three sizes of simulated lesion were investigated (2.5, 5.5 and 10 mm), which were randomly added to each selected anatomical region of adult radiographs with no known pathology. Detection performance was the lesion intensity ($I_{92\%}$) that produced a detection accuracy of 92% in 4 Alternate Forced Choice (4-AFC) experiments. We investigated how detection performance ($I_{92\%}$) varied as the display window width was varied by a factor of two (500 to 1000). **Results:** In the apex and hilum, reducing display contrast by a factor of two reduced detection performance by approximately 20%, and this was true for all lesion sizes investigated. In the sub-diaphragm region, the results obtained depended on the lesion being detected. For the large 10 mm lesion, reducing the display contrast by a factor of two also resulted in a drop in detection performance of ~20%, whereas for the smallest (2.5 mm) lesion, display contrast had no significant effect on detection performance (<5%). **Conclusion:** Changing the display contrast in chest radiography only has a modest effect on lesion detection. In the hilum and apex, the effect of image display on detection performance was the same for all lesion sizes. In the sub-diaphragm region, however, detection of small lesions was independent of image display contrast.

TU-C-I-609-06

Task-Based Optimization of Dual-Energy Imaging Systems Using Generalized NEQ

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Purpose: Dual-energy (DE) imaging is a promising advanced application of flat-panel detectors (FPDs) for early detection of lung cancer. This paper investigates the performance of FPD-based DE imaging systems by extending descriptions of generalized detective quantum efficiency (GDQE) and noise-equivalent quanta (GNEQ) to a task-based optimization of system design, image acquisition, and reconstruction. **Method and Materials:** This investigation incorporates anatomical noise into traditional descriptions of DQE and NEQ to yield the GNEQ for DE imaging systems. Imaging performance was calculated using cascaded systems analysis and combined with anatomical noise measured and modeled as $1/f$ noise. Calculations of GNEQ were combined with Fourier descriptions of imaging task to yield the detectability index, d', taken as an objective function for optimization of DE image reconstruction (tissue cancellation), kVp, added filtration, and allocation of dose between image pairs. **Results:** Analysis of GNEQ reveals a tradeoff between increased quantum noise and reduced anatomical noise in DE imaging systems. Optimal DE image reconstruction (i.e., selection of tissue cancellation parameter, w_t) was found to exhibit moderate task dependence, ranging from w_t=0.49 to 0.44 for gaussian detection and discrimination tasks, respectively. Optimal kVp pairs were identified as a function of imaging dose – e.g., (90 / 150 kVp) at high dose (1 mR), decreasing to (60 / 120 kVp) at low dose (10 uR). The analysis quantifies the potential improvement in performance associated with addition of high-Z filters (e.g., Cu, Ce, and Ta). For fixed total entrance dose, optimal allocation of dose between high- and low-kVp images depends on the imaging task, highlighting the tradeoff between quantum and anatomical noise. **Conclusions:** Experimental and theoretical analysis of GNEQ and task-based detectability index provides a fundamental understanding of the factors governing DE imaging performance and offers a powerful methodology for optimization of system design and image acquisition.

TU-C-I-609-07

Optimization of a Real Time Dual-Energy Subtraction Technique Based On a Flat Panel Detector

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Purpose: To determine the optimal x-ray spectra for dual-energy subtraction with a flat panel detector (FPD), and to quantify the effects of dynamic filtration and FPD gain settings on image quality, tube loading, patient exposure, and overall system performance. **Method and Materials:** A simulation study was performed using available empirically determined data of x-ray spectra. The lungs and mediastinum of the chest were modeled with 12.5 cm and 20 cm thick regions of Lucite, respectively. Coronary calcification was modeled with a 1 mm thickness of bone-equivalent plastic. The FPD was modeled as an ideal detector with a 600 micron thick layer of CsI. Scatter was not considered in this study. Low and high energy images were normalized to a desired energy deposit in the detector dependent on FPD gain. A figure-of-merit (FOM) was used to quantify the overall system performance. The effects of various silver filter thicknesses (0-1000 microns), high to low energy image signal ratios (1-8), and two dual-energy noise reduction algorithms were evaluated for their effect on image quality, patient entrance exposure, tube loading, and FOM improvement. **Results:** As the thickness of the high-energy filter increased, image contrast, contrast-to-noise ratio, FOM and tube loading increased. Patient exposure was reduced by approximately 10% for the range of filter thicknesses studied. The FOM was maximized with a FPD signal ratio of approximately 3 without application of dual-energy noise reduction. However, dual gain operation did not show any improvement after noise reduction. **Conclusion:** An optimal dynamic filter combined with dual-energy noise reduction can improve the system FOM by a factor of 5. There is no further improvement in the system FOM when dual detector gain is used in conjunction with dual-energy noise reduction.

TU-C-I-609-08

A Total-Imaging-System Generalized Performance Comparison of An X-Ray Image Intensifier and a Microangiographic System in Neurovascular Angiography: Effect of Focal Spot and Scatter

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Purpose: To quantify the total-system performance of an x-ray image intensifier and compare it with a microangiographic system in terms of the generalized metrics of GMTF, GNNPS, GNEQ, and GDQE which include the effect of geometric-unsharpness, scatter from the patient, as well as the detector characteristics. This presentation expands on our previous work with generalized imaging-system metrics to include a detailed study of the effect of varying the focal-spot. **Method and Materials:** A commercial x-ray image intensifier (XII) C-arm unit and a high-resolution ROI microangiographic detector were evaluated with reference to their

performance in neurovascular angiographic studies. The study was performed using clinically relevant spectra and conditions specific for each system. A uniform head-equivalent phantom was used, and images were acquired for 60 to 100 kVp at a source-to-image distance of 100 cm for the XII and 75 cm for the microangiographic system. The detector, focal-spot, and scatter unsharpness were quantified in terms of their respective MTF's, and the scatter fraction was determined. These were combined to express a Generalized MTF (GMTF) with spatial frequencies referenced to the object plane. The effect of varying field-size, air-gap and focal-spot size (0.3 mm and 0.6 mm nominal) was studied. A detailed total-system evaluation of the two systems was carried out in terms of the generalized performance metrics of GMTF, GNNPS, GNEQ, and GDQE. **Results:** The results of the GMTF and GDQE comparison of the two systems indicate that the microangiographic system performs substantially better than the II at higher spatial frequencies, as needed in image-guided, neuro-interventional procedures. Use of a smaller focal spot further improves its high frequency behavior. **Conclusion:** This generalized approach can provide a more realistic evaluation of total-system performance leading to improved system designs tailored to the specific imaging task.

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TU-C-I-609-09

Towards Low-Dose Soft-Tissue Visualization in Megavoltage Imaging: Initial Evaluation of a Prototype High Quantum Efficiency Segmented Crystal-Based Portal Imager

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Purpose: To demonstrate the potential for low-dose soft-tissue visualization at megavoltage x-ray energies using a novel, high-QE segmented CsI(Tl) detector incorporated in an active matrix flat panel imager (AMFPI). **Method and Materials:** A prototype AMFPI EPID was developed, incorporating a 40 mm thick, non-optimized, segmented detector comprised of 160×160 optically-isolated, crystalline CsI(Tl) elements spaced at 1016 μm pitch. The detector was coupled to an indirect detection-based active matrix array (508 μm pitch) - each detector element registered to 2×2 array pixels. Detailed quantitative characterization of the prototype imager was performed under radiotherapy conditions (6MV) to determine x-ray sensitivity, MTF, NPS and DQE. Images of a contrast-detail phantom and step wedges of low-contrast tissue equivalent materials were acquired at a dose corresponding to a single beam pulse. Monte Carlo simulations were performed to estimate the upper limits of the frequency-dependent DQE for this prototype EPID as well as for a variety of hypothetical segmented detector configurations. **Results:** The prototype imager exhibited over an order of magnitude higher DQE at zero spatial frequency compared to conventional AMFPI systems, with gradual fall-off at higher frequencies. Contrast differences between 1, 2 and 3 cm thick lung tissue phantom (density ~0.3 g/cm^3) overlying an ~1 cm thick acrylic slab were observed in projection images acquired at a single 6MV beam pulse. Finally, theoretical calculations suggest that DQE up to 50%, along with further improvements in MTF, may be achievable through further optimization of the segmented detector design. **Conclusion:**
The high DQE values and good contrast resolution exhibited by the prototype imager, as well as prospects for further significant improvements in DQE, open up the enticing possibility of obtaining soft-tissue contrast at clinically practical doses in megavoltage tomographic and perhaps, even projection imaging. This work was supported by NIH grant R01-CA51397

TU-C-I-609-10

Preliminary Study of Pixel Pitch and Effect of Divergence On Thick Cadmium Tungstate Detector

T monajemi*, B Fallone, S Rathee, Cross Cancer Institute, Edmonton, AB, CA

Purpose: To theoretically study the effects of pixel pitch and beam divergence on 1 cm thick $CdWO_4$ crystals for use in megavoltage cone beam computed tomography (MVCBCT). **Method and Material:** $CdWO_4$ linear array (80-elements, each 0.275 x 0.8 x 1 cm^3 in fan beam) has been proven to be a good candidate for MVCT in our lab. For this study, DOSXYZnrc Monte Carlo code was used to find the point spread function (*PSF*) as the distribution of energy deposited in a theoretical flat detector (30 x 30 x 10 mm^3, 0.01 x 0.01 x 10 mm^3 voxels). A pencil-beam of 6 MV photons was incident at a range of angles (0˚, 5˚, 10˚, 15˚, 20˚) with respect to the normal. In each case, the detector *PSF* (ignoring optical spread) was convolved with a realistic source function to give the system *PSF* in the plane of the object. A realistic object to detector magnification of 1.4 was used in the system *PSF* calculations. The *PSF* at 0.01 mm pitch was re-binned into several pitches (0.5, 0.7, 1.0 mm) and Fourier transformed to obtain the system modulation transfer function (*MTF*). **Results:** This analysis suggests an optimum pitch of 0.5 mm which cannot be fabricated using $CdWO_4$ because of the cleavage plane. However, the pre-sampled detector *PSF* is further degraded due to small optical leakage through reflective coating and scintillator-photodiode interface, and the scattered radiation from the object. So, in practice a pitch of 1 mm may be sufficient. The degradation of the system *MTF* with the increasing divergence is significant between 0˚ and 5˚, and becomes large at 10˚. **Conclusion:** Practical pitch of 1 mm is not ideal yet maybe sufficient. The use of flat panel photodiode arrays for MVCBCT is precluded due to divergence; instead a focused detector should be used.

Imaging Symposium Room 611

Advances in CT: Hardware, Algorithms, and Applications

TU-C-I-611-01

Recent Developments in CT Technology

W Kalender*, Univ Erlangen, Erlangen, DE

The first lecture in the symposium "The New CT" will cover recent developments in hardware. This relates to the scanner mechanics, the x-ray source, and the detector system, but also to new designs such as C-arm and micro-CT systems. The largest portion will be dedicated to detector concepts and characteristics.
With rotation times below 0.5 s, modern clinical CT systems pose increasing demands on the mechanical design of the scanner and of all its components. These are contrasted by the demands of C-arm systems using flat panel detector where rotation times are typically between 5 and 20 s.
Due to the increased rotation speed in clinical CT, x-ray power levels increase accordingly to allow for unimpaired image quality, in particular unaltered noise levels. The latest developments in x-ray source technology, which offer power levels of 80 to 100 kW, will be reviewed and explained.
CT detector technology has received remarkable interest in the past years. The continuous development from single-slice to multi-slice systems, including detectors allowing the simultaneous acquisition of 2, 4, 6, 8, 10, 12, 16, 32, 40, and 64 slices, has even been viewed as the "slice race" or the "slice war" in the media. The technological basis will be reviewed. In particular, the question if this development shall and will continue will be discussed. This also includes the potential role of flat panel detectors which have come into use with C-arm systems and which are now being used frequently for interventional CT and for CT angiography.
The presentation will conclude with a short review of dose management and micro-CT systems. **Conflict of Interest :** WAK is a consultant to Siemens Medical Solutions.

Educational Objectives:
1. to understand the detector concepts presently in use in clinical CT
2. to understand the distinction between multi-row detectors and multi-slice scanning
3. to understand the concepts and requirements for exposure control systems

TU-C-I-611-02

New Development of Imaging Theory and Algorithms in Computed Tomography

X Pan*, Univ Chicago, Chicago, IL

Computed tomography (CT), one of the most widely used imaging modality in medicine and other areas, is currently in a period of renaissance largely due to the advent of the helical cone-beam data acquisition technology. This new development has opened up tremendous opportunities for the design and applications of CT imaging protocols in medicine and other areas that would otherwise be impossible. On the other hand, the cone-beam CT also poses numerous theoretical and numerical

challenges on the algorithm development. One of such challenges is to the need of new theory for obtaining accurate images from helical cone-beam data to which the conventional CT theory is no longer applicable.

In this talk, following the introduction of the basic principle of CT imaging, the recent advances of CT technology and imaging theory/algorithms will be discussed. Emphasis will be placed on the description of the new concepts, theory, and algorithms that we have recently developed for image reconstruction from cone-beam data acquired with a wide variety of scanning configurations, including the helical scanning configuration. We also believe that one of the important trends in CT imaging is the so-called targeted imaging of a region of interest (ROI) within the subject from truncated data. Such a targeted imaging strategy would substantially reduce the radiation dose delivered to the subject, scanning effort, and/or data contamination from motion and other artifacts. Therefore, I will describe our approaches to and algorithms for exactly reconstructing ROI images from truncated or reduced data in cone-beam CT.

TU-C-I-611-03

Computed Tomography - What systems deliver vs. What clinicians Need

M. Vannier*, University of Iowa, Iowa City, IA

Computed tomography is the most important modality for many patients, since CT is the first and only examination they have before therapy or for followup. As the technology evolves, we observe changes the range of CT applications and its clinical utilization. We are in the midst of rapid expansion of clinical CT imaging use, due to increased speed and coverage, necessitating an evaluation of its current and potential future contributions. The needs of clinical medicine not yet met by CT, but potentially achievable in screening, diagnosis, therapy and followup are valid goals for technology developers. Despite intrinsic limitations due to use of ionizing radiation and substantial fixed costs, CT has room for growth and its technological evolution is not near the end.

Joint Imaging/Therapy Scientific Session Room 6B
Functional Imaging, Registration, and Fusion

TU-C-J-6B-01

From Morphological to Functional Definition of Organs at Risk: The Role of FMRI in Radiosurgery

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Purpose: functional magnetic resonance (fMRI) identifies areas related to different modality tasks. It is possible to identify particular areas in the brain which can be considered like “functional organs at risk” (fOARs). The aim of this study is to describe a method to exploit this functional information for the identification of fOAR in radiosurgery treatment planning. **Method and Materials:** for a patient who underwent radiosurgery treatment, CT and 60 EPI MR volumes were acquired for BOLD analysis of functional areas. Tasks were chosen on the base of the lesion location. The functional maps obtained by Statistical Parametric Mapping (SPM) software refer to the template volume: if one wants to exploit this information for patient treatment, it is necessary to calculate the deformation field which maps the template onto the CT. Treatment planning was performed using the CyberKnife radisourgery system. **Results:** the method has been applied to a patient with a right frontal metastasis of breast cancer. We have performed BOLD analysis of the motor function with self-passed left hand and left foot tasks, and of language related areas using category generation task (CGT), letter generation task (LGT), and simple questions task (SQT). It has been found that the activation of the 2 motor tasks was very close to the lesion while for the CGT, LGT and SQT studies the most significant constraint deals with the language associative areas located in the dorso-lateral frontal cortex (Brodman areas 8 –9). **Conclusion:** treatment plans studied with and without considering the fOARs were significantly different, in particular for the Dose Volume Histograms (DVH), while maintaining dose indices almost constant (homogeneity equal to 1.15 with fOARs and 1.18 without fOARs; conformity equal to 1 for both plans), proving a potential role of fMRI in radiosurgery.

TU-C-J-6B-02

Assessment of Tumor Proliferation During Radiotherapy

R Jeraj*, E Smith, D Barbee, D Dick, J Nickles, O DeJesus, E Ballegeer, L Forrest, University of Wisconsin, Madison, WI

Purpose: To explore the basis for quantitative in-vivo tumor imaging during radiation therapy with the aim to adaptively modify the treatment according to the response. **Method and Materials:** Two positron emission tomography (PET) imaging agents were used to assess the response. Fluorodeoxygluocose (^{18}F-FDG), a metabolic marker, is not ideal agent for monitoring tumor tissue response, because increased metabolism in response to radiotherapy due to inflammatory cells. 3'-deoxy-fluorothymidine (^{18}F-FLT) has recently been proposed as a marker for imaging tumor proliferation. Several canine subjects with recurrent soft tissue sarcomas were repeatedly imaged with PET/CT before, during and after the radiation treatment. The tumors were treated with ^{60}Co with one or two fractions of 8Gy. Approximately 200 MBq of FDG/FLT activity was administered per scan. Standard uptake values (SUV) were calculated to evaluate uptake in the tumor region, as well as in the surrounding organs. The CT data between the imaging sessions was co-registered and PET data compared. **Results:** Tumor response to therapy varied significantly between the subjects. High heterogeneity (up to 50%) of the tumor was observed in some of the cases. Early post treatment scans (3 days) showed already significant decrease in FLT uptake, followed by an increase 6 days after the treatment due to accelerated repopulation. Severe redistribution of the tumor proliferation potential was observed during the treatment. In the follow-up study 6-weeks post-treatment both, FDG and FLT PET showed low uptake in the tumor region (SUV=1.9 vs. SUV=1.0) with the slightly elevated FDG uptake on the periphery of the tumor. **Conclusion:** FLT proved to be a better treatment response monitoring agent than FDG. High heterogeneity of the proliferation activity, as well as redistribution of the proliferation potential indicates strong potential for treatment adaptation as well as potential problems with treatment planning.

TU-C-J-6B-03

Deformable Fusion of 4D PET Images

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Purpose: PET images are useful in defining treatment targets. Removing distortion from respiratory motion in the PET images is of importance for gated or 4D radiation treatments. We developed a deformable fusion method to sum up the PET images at different phases. The motion-blurring-free PET images are obtained without the sacrifice of signal to noise ratio (SNR) or increase of scanning time. **Method and Materials:** A GE Discovery CT/PET scanner was interfaced with Varian’s RPM breathing tracking system. 4D CT and 4D PET images were correlated according to the breathing phases. Full exhalation phase was used as the planning phase. Deformable image registrations of the 4D CT images yielded the displacement maps of the lungs relative to the planning phase. PET images at each breathing phase were then warped into the planning phase using the displacement maps. Motion-blurring-free PET images were obtained by summing the warped PET images. **Results:** Gated PET images at each individual phase are very noisy. The uncertainty from intensity fluctuations compromises the motion reduction by gating the scan. PET images are too fuzzy to be directly used in elastic registration. Instead, we registered the 4D CT images. With regular patient breathing patterns, 4D CT images correlate with 4D PET images. Consequently, the displacement maps from registration of the 4D CT images can be used in warping the 4D PET. Image warping removed the motion distortion in the PET images. The summed images have reduced motion blurring and the same SNR as that of non-gated PET images. **Conclusion:** Deformable fusion of 4D PET images reduce the motion distortion in PET image and retain the SNR without increasing data acquisition time. The resultant PET images can be used in more accurate target definition in gated or 4D radiation treatments.

TU-C-J-6B-04

Deblurring of Breathing Motion Artifacts in Thoracic PET Images

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Purpose: In FDG-PET imaging, blurring due to breathing motion can significantly degrade the quality of the observed image, which can obscure the delineation of the tumor boundary. We demonstrate a new deblurring

approach that combines patient-specific motion estimates of tissue trajectories with image deconvolution techniques to partially remove breathing-motion induced artifacts. **Method and Materials:** The human test data set consists of PET/CT co-registered images of patients diagnosed with lung cancer. The motion measurements are obtained using a breathing model developed recently at our institution. The model linearly maps tidal volumes and airflow measured by spirometry into spatial trajectories. The parameters of the model are fitted using a template matching algorithm applied to CT data. The motion model is used to locally estimate the point spread function (PSF) due to breathing. The deconvolution process is carried by an expectation-maximization (EM) iterative algorithm using the motion-based PSF. **Results:** We evaluated the proposed motion-based deblurring algorithm on idealized test data sets as well as two human PET images, one with a large and one with a small lung tumor. In this case, the estimated PSF would satisfy the shift-invariance property. Rescaling was used to correct for limited image support in the case of small tumors, which could lead to undesirable ringing effects (Gibbs phenomena). The initial results showed improvement in the spatial resolution, especially in the cranio-caudal direction. The EM algorithm converged within 20 iterations in both tumor cases. Generally, a compromise between entropy minimization and increase in MSE was used as a stopping criteria. **Conclusion:** We have implemented a method and algorithm for removing breathing motion from PET images. The initial results show that the method is promising for improving PET thoracic images.

TU-C-J-6B-05

A Novel Volume Subdivision-Based Algorithm to Register Respiration Phase-Correlated Lung CT Images

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Purpose: To develop a deformable image registration algorithm that will allow for temporal interpolation of phase-correlated 3D CT data sets and test it on lung CT images. **Method and Materials:** We have developed a new deformable image registration algorithm that starts with a global rigid-body matching between two (volumetric) images, progressively subdivides one image, and refines the spatial matching locally for each of the subvolumes. When subvolumes reach a user-defined size, the algorithm interpolates all local solutions to generate a smooth deformation field. The above algorithm was applied to two lung CT image sets, each with three frames corresponding to end-inhalation (IN), mid-exhalation (MID) and end-exhalation (EX). These images were acquired in conjunction with a spirometer and using a spiral CT scanner. In each case, the IN image was registered to the MID image and the MID image to the EX image. An interactive multi-planar reformatting tool was used to evaluate the result of image registration quantitatively. For quantitative evaluation, reduction in root-mean squared (RMS) error was computed for each image pair before and after image registration. **Results:** Visual inspection indicated an improved matching of anatomical features following registration. For the four image registrations performed (two for each case), the RMS error reduced from 13.8 to 7.2, 19.9 to 12.7, 13.5 to 8.0, and 12.2 to 7.0, indicating improved spatial matching following image registration. **Conclusions:** We have developed a new deformable image registration and shown its application to gated lung CT images. The algorithm effectively aligned phase-correlated CT images. Full development of this deformable registration capability will allow tumor trajectory mapping and dose registration.

TU-C-J-6B-06

Dynamic Contrast Enhanced CT to Improve Localization of the GTV Within the Prostate

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Purpose: To achieve a higher sensitivity and specificity in the localization of the GTV within the prostate using quantitative perfusion maps obtained from dynamic contrast enhanced CT (DCE-CT) imaging. **Method and Materials:**
DCE-CT tracks the passage of a bolus of contrast agent through the prostate in time.
With a 40 slice CT scanner we scan a large volume of the prostate with a high temporal (1.5 s) and spatial (0.5x0.5x5 mm) resolution. Moreover, because of the linearity between CT signal enhancement and contrast concentration increase, quantitative analysis is greatly facilitated. We calculate quantitative perfusion maps of the complete prostate by using the tissue homogeneity model, which determines the response of a voxel to the measured input bolus. Furthermore, we have performed an extensive signal-to-noise analysis to determine the optimum between voxel size and flow accuracy.
We have included 11 patients in our study with biopsy proven prostate cancer (stage T3). The CT exam was performed prior to external beam radiotherapy.

Results: For all 11 patients we have successfully calculated perfusion maps with an accuracy of 10% and a resolution of 1.5x1.5x5 mm. We find the average perfusion of the prostate to be 15 ml/100g/min, while the elevated regions have average values of 60-70 ml/100g/min. These hotspots, which are identified as the GTV, can be delineated in three dimensions based on the flow maps and are found to correlate well with the clinically known GTV. **Conclusion:** Using DCE-CT we can determine three-dimensional quantitative perfusion maps of the complete prostate. Elevated flow regions correlate well with the clinically known GTV, and may be of value to improve delineation of the GTV within the prostate.

TU-C-J-6B-07

3DUS, MRI and CT Prostate Volume Definition: 3D Evaluation of Intra- and Inter-Modality and Observer Variability

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Purpose: To produce a complete three-dimensional description of the accuracy, variability significance of differences in prostate volume estimation using 3DUS, MR and CT imaging. **Method and Materials:** Ten patients underwent 3DUS, MR (axial FSE T2-weighted) and CT imaging 28-33d after I-125 implant (74-112 seeds, mean=93.3). MR prostate volume range was 22.6-50.8cc (mean=31.9cc). Seven experienced observers contoured prostate volumes in 2.5 mm slice increments, twice for each patient, while blind to image duplication within and between modalities. Regional trends in variability and absolute differences in volume estimation between modalities were examined in 3D. **Results:** The average volume ratio was 1.16 for CT/MR, 0.90 for US/MR and 1.30 for CT/US. The greatest variability of CT contours occurred at the posterior and anterior portions of the mid-gland. On MR images, the overall variability was smaller, with a maximum in the anterior region. On 3DUS, high variability occurred in the anterior regions of the apex and base, while the prostate-rectum interface had the smallest variability. 3DUS contours tended to be larger than CT and MR in the anterior and posterior aspects of some patients, likely due to gland deformation by the US probe. The average percent of surface area that was significantly different (95% confidence) was 4.1%, CT-MR; 10.7% US-MR; 6.3% CT-US. Both center-of-mass registration and larger standard deviation of CT measurements increase statistical similarity of CT to other modalities. Using seeds as fiducial markers decreases this similarity. Deformation during insertion of the trans-rectal ultrasound probe, rectum and bladder filling and breathing motion also have an effect. **Conclusion:** Our findings suggest that improved seed recognition algorithms for 3DUS or MR, or fusion with CT may improve the accuracy of post-implant planning. Visualization of 3D trends between modalities may assist in improving the consistency of prostate delineation.

TU-C-J-6B-08

A Variational Deformable Image Registration Method Capable of Handling Large Organ Deformation

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Purpose: The goal of this research is to develop an accurate and reliable deformable image registration algorithm capable of handling large organ deformations for mapping daily CT images to the reference planning CT. **Method and Materials:**
We previously developed a diffusion-based deformable image registration algorithm using Thirion's "demons" algorithm. However, this

implementation did not work well when large deformations occurred. In this study, we proposed a variational approach for deformable image registration within a multigrid computational framework. The differences of the two images were measured and minimized, and a regularization term was introduced to rule out discontinuities and other irregular solutions. In our numerical implementation, the well-studied multigrid method was used for solving the nonlinear Euler-Lagrange partial differential equation (PDE). In this multigrid approach, the results from the previous deformation field were used to initialize the next stage of deformation. Different smoothing parameters were also used at different stages. The solution to these PDEs gave the displacement fields which can be used to transform the daily CT images into the planning CT or vice versa. To test this approach, we performed deformable image registration using CT images of prostate cancer patients collected with an in-room CT-on-rails system under an IRB-approved protocol.

Results: Daily CT images were selected for cases with severely distorted rectum (due to the presence of large bowl gas) or large variations in bladder filling. The results indicated that the proposed approach was capable of deforming very large shape changes of soft tissue or organ structures. Compared to the "demons" algorithm, the resulting registration was pronounced better visually and quantitatively using both distance and correlation measures. **Conclusion:** Our deformable registration approach demonstrated the capability of handling large deformations. Further validation studies need to be done to test its robustness.

TU-C-J-6B-09

Automatic Contour Delineation On Subsequent CT Images Using Deformable Registration

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Purpose: To implement a deformable registration algorithm to automatically delineate regions of interest (ROIs) on daily CT images by transforming the corresponding ROIs from a reference CT image. **Method and Materials:** An intensity-based 'Demons' deformable registration algorithm was used to find the correspondence between planning CT image and daily CT image. After reference ROIs were delineated manually on the reference CT image, the reference ROIs can be mapped onto each daily CT image. We tested this method on one head-and-neck patient (tonsil tumor). The patient received 3 CT scans per week prior to treatment for a total of 16 CT scans. The deformed ROIs were visually evaluated by a radiation oncologist. The dose-volume histograms (DVHs) of the deformed left and right parotids were calculated and compared with the planned DVHs. In addition, a cumulative dose distribution was calculated by mapping the daily dose distribution from each of the daily CT images back to the planning CT using the deformable registration method. Thus, the DVHs from the cumulative dose distribution can be calculated to represent the final "delivered" dose distribution. The volumetric changes during the elapsed treatment days for targets and critical structures were also investigated. **Results:** The deformed contours reasonably matched with gross anatomy presented by the CT images. The daily DVHs showed a large variation during the course of treatment due to both setup errors and internal organ deformation. In spite of large variation in DVHs of the parotids in daily CT images, the DVHs of the cumulative dose agreed reasonably well with the planned DVHs for both parotids in this case.
Conclusion: We demonstrated that an intensity-based deformable registration algorithm can be used effectively to map the planning ROIs to subsequent CT images acquired during treatment. This allows effortless replanning in an adaptive CT-guided radiotherapy strategy.

Joint Imaging/Therapy Symposium Room 6C
How Complex Does Photon Technology Need to Be?

TU-C-T-6C-01

Introduction: "How much complexity is necessary for IMRT?

L Verhey*, UC San Francisco, San Francisco, CA

IMRT treatment planning and delivery systems have developed rapidly over the past 5 years. Every manufacturer of linear accelerators now offers IMRT delivery systems using multileaf collimators and some sort of automated delivery scheme. Most treatment planning systems now offer "inverse" planning algorithms that optimize fluence and dose distributions given a set of dose constraints for tumors and normal tissues. For some accelerator manufacturers, the output of the planning system is a set of multileaf shapes, or "segments" with associated intensities, which combine to give a variable intensity distribution for each beam angle. This delivery system is referred to as static multileaf IMRT (or SMLC). For others, the intensity distribution is continuous and the leaves move with variable speed across the field with the beam remaining on. This is called dynamic multileaf IMRT, or DMLC. SMLC tends to be somewhat time consuming relative to conventional delivery, as there is overhead due to communication between the MLC controller and the accelerator. For DMLC, very little time is lost relative to conventional beam delivery times.

Most IMRT planning systems have a mechanism for controlling the complexity of the resulting plan, which is determined by the number of beam angles and the number of intensity levels specified in the plan. Highly complex plans are those that end up with large numbers of beam segments and small monitor units per segment, translating into rapid dose gradients within the patient. These are presumably desirable when a tumor is immediately adjacent to a very sensitive normal tissue and the dose falloff must be rapid outside the tumor border. On the other hand, dose delivery errors are expected to be greater with highly complex plans, since the dosimetry of small fields and the linearity of the dose at small numbers of monitor units, are rather uncertain. This fact drives us to limit the complexity as much as reasonably possible. Since DMLC does not have a significant time penalty for high complexity, there is a tendency to plan highly complex IMRT for these delivery systems. For SMLC, the constraints of treatment time tend to drive the planner to choose less complex solutions. The question to be addressed in this Symposium is how much complexity is necessary for IMRT. Clearly, the answer is site-dependent, but even at a given site, the answer is not clear. Today's speakers will describe the incentives for simplicity (time and dose accuracy), methods of controlling the complexity and the tradeoffs between complexity and conformality.

TU-C-T-6C-02

Simplifying IMRT with Direct Aperture Optimization

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Earlier and more widely used method for IMRT planning is beamlet-based inverse planning. It divides each beam into beamlets or bixels in the same way as planar images are composed of pixels. A computer algorithm is then used to optimize the weights of these beamlets. The optimized weight distribution is also called intensity maps. In order for the desired intensities to be delivered, a leaf-sequencing algorithm is used to translate the intensity maps into a sequence of deliverable beam shapes called segments. This two-step process (intensity optimization and leaf sequencing) puts delivery consideration outside the optimization and complicates IMRT.

In beamlet based inverse planning, optimizing the intensity distributions is only the first step of the planning process. Leaf sequencing, or creating a desired beam intensity using overlapping MLC shapes, is a mathematically intractable problem. A large number of complex field shapes are often needed. This can lead to a loss in efficiency and an increase in collimator artifacts. Attempts have been made to simplify the delivery by either grouping the intensity levels or smoothing the intensity distributions. However, such attempts are always accompanied by the reduction of plan quality. When a large number of segments are used, there are typically segments requiring a low number of monitor units (MUs) along with small off-axis fields. These segments introduce new challenges for accurate dose calculation and unrealistic requirements for geometric accuracy of the MLC and dosimetric accuracy of the linear accelerator. As the result, QA efforts must be intensified in order to achieve the well-established safety and accuracy standards.

Realizing that this two-step process and the large number of beam segments resulting from the poor process are the root causes of the labor intensive nature of IMRT, we directly optimize the beam apertures and their weights. This method is termed "Direct Aperture Optimization (DAO)". With DAO, only a few segments are needed to generate treatment plans that rival those produced by employing the two-step process. Most importantly,

what you see is what the patient will get, since all the delivery related effects are already included in the dose distribution and the beam segments generated by the plan can be directly transferred to the linac for delivery.

In this presentation, we will describe the DAO process and compare it with beamlet-based inverse planning. We will show that the number of segments can be drastically reduced without affecting plan quality. We will also show that the effects of organ motion are inversely proportional to the segment size and segment MUs. With reasonably sized field segments, the requirement for MLC geometric accuracy and linac's dosimetric accuracy will be significantly lessened and the need for extensive QA will diminish. The delivery time will also be in line with conventional practice allowing more patients to receive the benefits of IMRT. The effects of organ motion during IMRT delivery will also be smaller.

TU-C-T-6C-03

Simplifying IMRT Plans Through Efficient Segmentation

R Siochi*, University Of Iowa, Iowa City, IA

Purpose: To analyze the various methods for creating efficient leaf sequences for an IMRT plan, subject to MLC constraints. **Method and Materials:** An IMRT treatment plan can be simplified at several stages. Careful beam placement can lead to simpler intensity maps. The choice of the dose optimization engine, as well as the spatial and intensity resolution can also affect map complexity. To further reduce the total number of segments and monitor units, an optimal leaf sequence must be used. This reduction is accomplished by a combination of segment extractions and sweeps. The algorithms involve the determination of MLC shape and MUs. Some algorithms use predefined MUs according to a sequence (e.g. Power of two, Half-Maximum, Triangular numbers), while others optimize the MU selection by evaluating the complexity of the difference between the intensity map and the segment being considered. The selection of the MLC shape can also be achieved through a predetermined geometric process (e.g. largest area, largest area with maximum intensity, leftmost segment, graph theory) or by minimizing the complexity of the difference map. In this step, the machine constraints and the desire to reduce the tongue and groove effect are considered, as they can dramatically increase the number of segments and MUs. Once the leaf sequences have been generated, an examination of the plan may reveal degradation in the DVHs, and appropriate leaf-sequence modifications can help restore the plan quality. **Results:** Plans with beams that have minimal critical structure involvement and modulate with more leaves yield less segments and MUs. Optimizers that use gradient methods rather than simulated annealing tend to reduce modulation scaling factors by a factor of 2 to 3. A map resolution of 10 to 15 intensity levels and a leaf spacing of 6 mm produce a reasonably efficient plan without sacrificing its quality, provided that the leaf sequence is optimized by minimizing the difference map complexity. The collision constraint increases the number of segments and MUs by about 20%, and various levels of tongue and groove correction provide an additional increase of about 20 to 30%. Post processing can remove low weight segments, and leaf positions can be adjusted to eliminate hot and cold spots. **Conclusion:** In order to simplify an IMRT plan, one must take advantage of all the options that affect the leaf sequencing process, including beam placement, map resolution, segmentation algorithm choice and post-processing.

Educational Objectives:

1. To understand the importance of beam selection and set-up prior to plan optimization.
2. To know the impact of map resolution set-up on complexity and the achievement of clinical goals.
3. To know the limitations and strengths of the various algorithms for leaf sequencing and how to choose the appropriate one.
4. To become familiar with the post-processing of leaf sequences.

TU-C-T-6C-04

Quantifying the Tradeoff Between Complexity and Conformality

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Purpose: Complex intensity maps in an IMRT plan may have several undesirable effects: increased leakage and integral dose, higher sensitivity to delivery errors, longer treatment time. On the other hand, the potentially negative impact of a reduction of the complexity on the dose conformality is not a priori clear. We propose to study the interplay between complexity and dose conformality in an interactive multi-objective planning approach. **Method and Materials:** Two surrogate measures of complexity have been studied in previous approaches: The number of multileaf collimator (MLC) segments (in step and shoot IMRT delivery), and the number of monitor units (MUs). The first is difficult to incorporate into optimization strategies because it is an "NP hard" problem and the calculation would be time prohibitive. Fortunately, one MLC vendor has proven that the MLC hardware and control software can be designed such that the pure number of MLC segments is not a limiting factor anymore. We therefore use the number of MUs as the measure of complexity. Mathematically, the number of MUs is given by the sum of positive gradients of the intensity map along the direction of leaf motion. We include the sum of positive gradients as a linear objective function in our plan optimization framework. In our approach we find solutions that are Pareto optimal, i.e., their complexity cannot be further reduced without compromising conformality. The results are incorporated into an interactive plan navigator by means of a "complexity slider", which allows the user to interactively explore the impact of a change of the plan complexity on the dose distributions. **Results:** Examples of optimized IMRT plans in the head and neck region and in the prostate will be presented. The potential of reducing complexity is case dependent but in comparison with current IMRT planning approaches a substantial reduction of the number of MUs (in the order of 20%) is often achievable without compromising the dose distribution. The complexity slider allows one to explore the whole spectrum of plans including the extrema, i.e. simple but not conformal or highly conformal but complex plans. **Conclusion:** The complexity of an IMRT plan can be limited or reduced with various methods. In general there is a price to be paid for this. Multi-objective optimization can help to find the most suitable tradeoff.

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TU-C-T-6C-05

How Much Complexity Is Necessary for IMRT?

J Galvin*, Thomas Jefferson Univ Hospital, Philadelphia, PA

The key to simplifying IMRT is keeping the intensity patterns as simple as possible. Of course, any simplification of the intensity distributions might degrade the quality of the final treatment plan. A major problem is that it is hard for the dosimetrist to determine if a current iteration of a treatment plan is as good as possible. Not knowing if changing the dose constraints one more time will give a better result, it is difficult to justify simplifying the intensity pattern as part of the inverse planning process.

However, the drawbacks associated with busy intensity patterns are well known. There are basically two problems that are related, but affect the overall process in different ways. First, complex intensity patterns can increase the number of segments needed to model the distribution. This can increase multileaf collimator wear and extend treatment times. Second, complex intensity patterns can drive up monitor units with a likely increase in the leakage radiation reaching the patient's total body.

There are some delivery systems that can relatively easily handle busy intensity patterns. Examples are tomotherapy and dynamic multileaf delivery. It is not clear that these approaches avoid the basic problems that are the justification for trying to simplify the intensity patterns. This presentation argues that it is important to optimize the dose optimization process such that the quality of the dose distribution is within acceptable limits while keeping the intensity pattern as simple as possible.

There are methods for evaluating the quality of treatment plans developed during the inverse planning process. In addition to relying on previous experience in planning similar cases at your institution, it is possible to review readily available RTOG protocols to determine how a group of experts define acceptable dose volume histograms for treating a particular disease site with IMRT. There is a nasopharynx protocol and another for

treating oropharynx lesions. Other RTOG protocols have been written or amended to include IMRT as an option. These additional protocols have more expanded statements of the required DVH constraints needed to accommodate the use of IMRT. The information that exists in RTOG protocols helps the dosimetrist set the dose volume constraints that must be met during the inverse IMRT planning process, and then concentrate on simplifying the intensity pattern as much as possible while staying within these stated limits.

There are a number of methods available for simplifying the intensity patterns obtained from the inverse planning process: 1) It is possible to use an inverse planning algorithm that inherently produces simple intensity patterns. 2) Some interpreter software used to model the intensity pattern reduces the number of segments and monitor units. 3) Deriving the field segments during the optimization process (Direct Apertrure Optimization) can decrease segments and monitor units. 4) Up-front geometric aperture design reduces the number of segments that the inverse planning algorithm can use in finding an acceptable solution to the treatment planning problem.

This presentation will discuss the techniques available for simplifying the overall IMRT process.

Professional Symposium Room 618

Medical Physicist Provider Status and Direct Billing: Legislative, Regulatory and Practical Implementation Issues

TU-C-P-618-01

Part I: Legislative and Regulatory Status

G White*, Chair, AAPM Professional Council, Colorado Associates in Medical Phys, Colorado Springs, CO

Clinical Medical Physicists do not currently have provider status and thus do not bill patients or their third party payors directly for patient specific services. If Medical physicists were to participate in the direct billing process in the U.S. Healthcare system, both legislative and regulatory changes would be required. Changes to Federal statures and the Code of Federal Regulations that would be necessary to enable direct billing will be described. In addition, the process for modification of Current Procedural Terminology (CPT) codes and their associated valuation levels (maintained by a combination of voluntary professional Societies and the Center for Medicare and Medicaid Services) will be reviewed.

TU-C-P-618-02

Part II: Practical Implementation Issues: Panel Discussion

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Panelists will discuss the practical issues associated with a change to direct billing by Medical Physicists. Implementation of Legislative, Regulatory and Reimbursement System changes and practical issues associated with the third party payor system and associated professional practice and business issues will be discussed.

Therapy Scientific Session Room 617

Stereotactic

TU-C-T-617-01

A Computer Model for Automatic Planning and Optimization for Gamma Knife Radiosurgery Using Auto-Positioning System

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Purpose: This research addresses the automatic-planning of Gamma Knife radiosurgery using auto-positioning system (APS). We previously reported a morphology-guided automatic planning model via optimization of dose conformity and minimization of total number of shots with different collimator sizes. In this work, our goal is to develop an optimization model that is adaptive to APS by using shots with same collimator. **Method and Materials:** Our three-step optimization strategy is: (1) configure the initial shot set using a combined process of skeletonization and bin-covering, (2) optimize the relative weight (exposure time) of each shot to improve target coverage while minimizing normal tissue toxicity, and (3) fine-tune the shot configuration by adjusting shot locations, and adding or deleting shots to further improve the balance between target coverage and normal tissue toxicity. In the weight optimization phase in step 2, an easy-to-solve linear fractional program explicitly models the dual objectives and takes into account of dose-renormalization (i.e., maximum is always renormalized to 100%). The fine-tuning step explicitly takes into account of shot overlapping, dose renormalization and target shape thus making the tracking of hot spots and estimating the effects of shot movement, addition and/or deletion possible. **Results:** We have implemented this optimization model on the Windows-based platform and have tested it with seven previously treated clinical cases. The target volume ranges from 2.6 to 8.6 cc, while the number of shots used ranges from 13 to 39. Our computer model generates plans in 1-2 minutes, with compatible quality of physician's plans normally created in 1-4 hours. The target coverage is greater than 95% and PITV ranges from 1.29 to 2.26.

Conclusions: Our computer model can be used for real-time planning, or for generating an initial plan followed by interactive optimization/fine-tuning, or for creating multiple plans with different trade-off objectives.

TU-C-T-617-02

Accuracy of GammaKnife Stereotactic Space Localization as a Function of Patient Alignment During Imaging

G Cernica*, Z Wang, H Malhotra, S de Boer, M Podgorsak, Roswell Park Cancer Institute, Buffalo, NY

Purpose: To establish the accuracy of stereotactic space localization for image sets where there is misalignment of the patient's head (stereotactic frame and fiducial box) relative to the CT- or MR- scanner axis. **Method and Materials:** Seven 0.5-mm diameter steel spheres separated by 2 cm were rigidly mounted to a string tied tightly at each end to diametrically opposite posts attached to a Leksell stereotactic frame. The steel spheres spanned the entire stereotactic space. A standard CT fiducial box was applied to the frame in the usual clinical manner. A baseline CT scan (1 mm slice thickness) was obtained with the fiducial box perfectly aligned with the scanner axis. After localization of the image set, the (x,y,z) coordinate of the center of each steel sphere was recorded. The frame was then repositioned, re-aligned and re-scanned and the coordinates re-obtained to verify reproducibility. Repeat CT scans with varying fiducial box misalignments up to 20 degrees in the sagittal, coronal, and transverse axes, respectively, were subsequently obtained. After localization, the (x,y,z) coordinates of the steel spheres in each misaligned image set were recorded and compared to the baseline coordinates.

Results: The mean difference between the baseline and the respective coordinates in misaligned geometries was 0.25 mm (σ=0.16 mm). The largest difference (0.87 mm) was found with the greatest misalignment in the coronal plane. These errors are within the accuracy of the image sets. **Conclusion:** Accurate localizations were obtained for image sets with misalignments up to 20 degrees relative to the CT- or MR- scanner axis. Patients with very inferior frame placements or concomitant medical conditions that prevent perfect alignment without significant discomfort can be positioned comfortably but rigidly and, despite misalignment with the CT- or MR- imaging axis, the fiducial box will nonetheless afford an accurate localization of the stereotactic space.

TU-C-T-617-03

A Geometrical Method for Lesion Placement in Functional Radiosurgery

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Purpose: To develop a rigorous mathematical method enabling precise navigation through stereotactic space to functional radiosurgery targets not visualized by any imaging modality. **Method and Materials:** In radiosurgery for functional disorders, Schaltenbrand-Wahren scaling formulas are often used to identify the appropriate target relative to imaged

brain anatomies. Stereotactic frame alignment relative to internal brain anatomy is therefore critical, and, consequently, the success of the treatment can be limited by frame misalignments. A mathematical method through which one can define directions in the brain was developed. Such a method enables accurate navigation to appropriate targets based on visible anatomic landmarks regardless of frame positions. The procedure was tested for GammaKnife thalamotomy, where the target is the ventrolateral nucleus of the thalamus. Small simulated targets were placed between three consecutive slices of a head phantom to provide CT-visible anatomy consistent with the Schaltenbrand-Wahren brain atlas. Scaling formulas were then used to navigate from the anterior and posterior commissures to the ventrolateral nucleus, where an additional marker was placed. Other markers were placed along the brain's midplane. A stereotactic headframe was then attached to the phantom four separate times: once with optimal alignment based on external anatomical markings, and 3 times with varying misalignments. The phantom was CT-scanned (1 mm slice thickness) with each frame attachment. **Results:** Over all image sets, the average distance between the predicted ventrolateral nucleus and its imaged location was 0.64 mm (maximum of 0.95 mm with greatest frame misalignment), consistent with imaging uncertainty. **Conclusion:** It is difficult to align a stereotactic frame to internal anatomy based on external landmarks. A mathematical method independent of frame placement has the potential to improve the accuracy of functional radiosurgery and to lessen the importance of ideal frame placement. Furthermore, this method can be used to confirm lesion placement in functional radiosurgery.

TU-C-T-617-04

Beam Configuration of Photon-Based Stereotactic Radiosurgery

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Purpose: Unequivocally, the experience of Gamma knife has set a solid notion pertaining to the definition and the dosimetric requirement of radiosurgery. Any newer, post-Gamma knife, radiosurgery system has to demonstrate comparable targeting precision and sharp dose gradient characteristics.

Statistics shows that the total of number of beams used in Cyberknife treatment is often less than 200. Herein, we present a study to evaluate the dose distribution characteristics comparing with that of the traditional photon-based radiosurgery. **Material and Method:** An experimental beam path with beam positions (notes) distributed in 2π solid angle was created to compare the dose distribution of

a. Single isocenter plan with different collimator sizes and with the total number of beams ranging from 30 to 205.

b. Multiple isocenter conformal plan and non-isocentric inverse conformal plan.

c. Multiple non-coplanar beam arrangement and Multiple coplanar beam arrangement

Results and Discussion: For single isocenter plans, no significant differences were observed in isodose levels ranging from 90% to 10%, with number of beams ranging from 55 to 205, distributed over 2π solid angle. With beam number reduced to 50, the noticeable differences fall in the dose levels under 10%.

The conformal planning using multiple isocenters increases the number of beams geometrically, while no-isocentric inverse planning can achieve excellent conformity with much less number of beams. However, close attention is needed to assure the dose fall-off is well controlled in all directions.

Although the reduction of beam number may not affect significantly the dose gradient in the median-high dose region, to deliver all beams in a single plane does result in a much inferior dose distribution. The attempt to use a single co-planar delivery for radiosurgery is thus to be avoided.

TU-C-T-617-05

Effect of MLC Leaf Width and PTV Margin On the Treatment Planning of Intensity-Modulated Stereotactic Radiosurgery Or Fractionated Stereotactic Radiotherapy

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Purpose: To investigate the effect of MLC leaf width and PTV margin on intensity modulated radiosurgery (IMSRS) and radiostherapy (IMSRT) dose distributions. **Method and Materials:** Twelve patients previously treated with IMSRS or IMSRT were retrospectively planned with a 5mm or 3mm MLC leaf width and a 3mm or 2mm PTV margin using the already contoured CTV, critical structures and organs at risk (OARs). The same beam arrangement, planning parameters and plan selection criteria were used in each four plans for a given patient. Same target coverage was achieved by renormalizing each plan so that the prescription dose covered at least 99% of the PTV. Plan indexes – D_{max}, D_{min}, and D_{mean}, conformity index (CI), V_{70}, V_{50}, D_{95} and V_{95} were calculated from the dose-volume histograms of PTV, normal tissue, or OARs. Ratios of plan indexes were computed and hypotheses tests were performed on the mean ratios to determine the significance of the relative changes. **Results:** The PTV was well covered for all plans. The PTV was 25% smaller when 2mm instead of 3mm PTV margin was used; CI of 3mm MLC was 7% lowered than that of 5mm MLC. The decrease of MLC leaf width had a similar effect as that of PTV margin in reducing V_{70} and V_{50} of the normal tissue and D_{mean} of brainstem by ~10%. However, D_{mean} of optic nerve and chiasm was more sensitive to the change of PTV margin. **Conclusion:** For IMSRT, the combination of 5mm MLC and 2mm PTV margin is dosimetrically equal to that of 3mm MLC and 3mm PTV margin for both PTV coverage and normal tissue sparing. The use of 5mm MLC and 2mm PTV margin for IMSRS is problematic because V_{70} and V_5 are ~10% higher than that of 3mm MLC and 2mm PTV margin.

TU-C-T-617-06

Importance of Pre-Fraction Helical CT Isocenter Verification in Extracranial Stereotactic Radiosurgery

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Purpose: To quantify the impact of pre-fraction helical CT isocenter verification vs. setup based on planning CT in fractionated extracranial stereotactic radiosurgery. **Method and Materials:** Treatment plans (Elekta PrecisePlan) and pre-fraction isocenter verification helical CT scans for 12 patients (40 fractions) were recovered from treatment plan archives. All structures were contoured by a single physician at the time of treatment. Each plan was imported into a customizable treatment plan analysis suite (CERR). Using CERR, pre-fraction isocenter verification CT scans were fused with the original treatment plan using the external body frame as a reference. The original planned dose distribution was then translated from original treatment plan isocenter to pre-fraction verification isocenters in each fraction. Dose and volume parameters for pertinent structures were automatically extracted using both registration methods (planned or pre-fraction scans) for the original treatment plan and for all subsequent fractions. All patients were treated using the pre-fraction verified isocenter rather than pre-calculated body frame fiducials as per our institutional policies. **Results:** GTV volumes on pre-fraction CTs varied from original planned GTV volume (64%-203%, mean=101.8+/-26.5%) largely due to helical sampling of a mobile target. Using the external body frame as the only setup reference would have resulted in geographic misses (<80% coverage of 95% of GTV) in 7/40 (17.5%) fractions. Pre-fraction isocenter verification resulted in improved D95 GTV coverage (88-102%, mean=99.3% +/-2.4%) with no geographic misses. **Conclusion:** The current RTOG protocol (0236) evaluating extracranial stereotactic radiosurgery does not require pre-fraction CT tumor position verification. Our institutional policy is to verify isocenter/tumor position prior to each fraction via CT. Although helical scanning artifacts are present, pre-fraction CT-based isocenter verification may provide more consistent tumor coverage than setup to planned body frame fiducials.

Conflict of Interest: Support for this research was provided in part by Elekta, Inc.

TU-C-T-617-07

Optimal Configuration of a Dedicated SBRT Treatment Unit for Radiation Therapy of the Lung

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Purpose: In the interest of optimizing lung stereotactic body radiation therapy (SBRT), the operating characteristics of a new dedicated unit with high-resolution MMLC, tunable energy range, and removable flattening filter were assessed. The system provides cone-beam CT capabilities for image-guided placement of the treatment isocentre. Measurements, Monte Carlo (MC) simulations, and treatment planning trials were initiated to allow rational selection of the optimal operating characteristics of this device in the management of lung cancer. **Method and Materials:** In this study, two theoretical models were created: one using the convolution/superposition (C/S) algorithm and the other using the MC simulation (BEAMnrc05) of the treatment head. The models were validated through comparison with measurements made using water tank (CC08-0.08cm3 volume, Wellhofer ion chamber) for a range of operating points of the accelerator (energy and presence of flattening filter). In addition, normoxic PAG gel measurements with MR-based readout were performed in order to assess the 3D dose performance.

Results: The MC and C/S models reproduced the measured dose distribution in water with an accuracy of 2% or 1mm. Modification of the beam energy decreased the dose rate from 675MU/min (6MV) to 56MU/min (~3MV). Removal of the flattening filter increased dose rate by a factor of 1.5-2 and a ~5% reduction in the 80%-20% measured penumbra in water. On-going planning studies will provide assessment of these changes on realistic clinical scenarios in the context of lung SBRT. **Conclusion:** A flexible treatment-imaging platform has been installed in our facility for SBRT. Selection of optimal operating point for this device for lung SBRT is being pursued. The removal of the flattening filter showed some merits for the recovery of dose rate and the decrease in penumbral width. Further studies are needed to identify the best machine configuration for lung SBRT. **Conflict of Interest:** supported by Elekta

TU-C-T-617-08

Peripheral Doses in CyberKnife Radiosurgery

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Purpose: To measure doses delivered outside of the irradiated volume for typical CyberKnife treatments and to compare the results to peripheral doses arising from similar Gamma Knife (GK) and IMRT treatments. **Method and Materials:** CyberKnife treatment plans were developed for two hypothetical lesions in an anthropomorphic phantom, one in the thorax and another in the brain. In both cases, 500 cGy was prescribed to the 70% isodose line. Li-F TLD-100 capsules were placed within the phantom at various depths and distances from the irradiated volume. For the brain lesion, GK and 6-MV IMRT treatment plans were also developed, and peripheral doses were measured. **Results:** Peripheral doses for the CyberKnife thorax treatment ranged from 3.3±0.13% to 1.2±0.06% of the prescribed dose (D_p) at distances between 15 and 43 cm from the edge of the target. For the target in the brain, CyberKnife peripheral doses ranged from 1.2±0.02% to 0.32±0.02% of D_p at distances between 18 and 71 cm from the target edge. In comparison, the GK peripheral dose ranged from 0.63±0.03% to 0.053±0.002% of D_p, and the IMRT plan resulted in doses between 0.19±0.004% and 0.043±0.002% of D_p over the same range of distances. **Conclusion:** Doses outside the irradiated volume for Cyberknife treatments are significantly higher than those encountered in standard radiation therapy. Peripheral doses given in AAPM Task Group Report No. 36 (Stovall, et al. Med. Phys. 22:63-82, 1995) for a 6-MV beam are between 0.2% and 0.02% of the dose at d_{max} at a distances ranging from 20 to 70 cm from the edge of a 5x5cm^2 field. Furthermore, for the same target in the brain, CyberKnife peripheral doses were a factor of 2 to 6 times larger than those for GK, and a at least a factor of 6 times larger than those for IMRT.

TU-C-T-617-09

Role of CT, and MR Angiographies in Accurate Target Volume Definition of Patients with Cerebral Arteriovenous Malformations (AVM) Treated with Stereotactic Radiosurgery

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Conventional angiography used to delineate cerebral AVMs is an invasive technique, and associated with significant risks as well as costs. Numerous publications have proposed CTA, and MRA for stereotactic planning of AVM in place of conventional angiograms. The purpose of this study is to evaluate the role of CTA, MRA, and fused CTA and MRA images in accuracy of AVM target volume definition for patients treated with stereotactic radiosurgery. **Materials and Methods**: 8 patients (12-58 years old) who underwent SRS treatments with a Brainlab Novalis SRS system for cerebral arteriovenous malformations (AVM) were retrospectively studied. The CTA was acquired using a GE dual slice CT, with 90 cc nonionic contrast injected to a peripheral vein at a rate of 3cc/sec, 15 seconds prior to the spiral CT acquisition. The MRA was acquired using a GE MRI system that includes vascular time of flight SPGR pulse sequences. The CTA was used for stereotactic localization as well as target volume definition. The CTA and MRA datasets were co-registered using the Brainlab's planning software. The AVM target volumes were contoured using the fused images by an expert reference observer. Three independent observers using CTA, MRA, and fused images independently contoured the nidus. The calculated average target volumes for each patient contoured by the 3 observers were plotted against AVM volume outlined by the reference observer. A linear regression analysis was performed on the curves. **Results:** The linear regression analysis yielded a slope of 0.96, 0.96, and 1.03 using MRA, CTA, and fused images, respectively. The study showed accurate nidus definition is possible by using either CTA, or MRA. However, using the fused images yield more precise AVM target delineation. **Conclusion:** Precise AVM target volume definition is possible by utilizing CTA, and MRA fused images for stereotactic radiosurgery.

TU-C-T-617-10

The Use of a Miniature Multileaf Collimator in Stereotactic Proton Therapy

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Purpose: To evaluate - in terms of dose conformity, neutron dose, activation, and leakage - the use of a Miniature Multileaf Collimator (MMLC) in stereotactic proton therapy, both as an aperture and for segmented intensity modulated proton therapy (IMPT). **Method and Materials:** Firstly, we compute the neutron production and activation of the MMLC with Geant4. In a simple geometry - a cylindrical target hit by a pencil proton beam – we determine the neutron distribution as function of position and energy, and compare tungsten, brass, nickel, and lead. Given the point-spread functions, we assess the secondary-neutron dose to the patient for the different materials and MMLC distance to patient. Secondly, we model the Radionics ConforMAX™ MMLC as integrated in our stereotactic proton beamline, and compare the dose distributions for the MMLC and an equivalent aperture. The results are validated with radiographic film measurements. Finally, we measure the proton leakage, activation, and neutron dose. **Results:** The neutron production in tungsten, the leaf material in most MLC's, is more than twice that of nickel. For a 10 cm diameter field, with a range of 15 g/cm^2 and modulation of 5 g/cm^2, and with the MMLC positioned at 30.0 cm from the patient, the maximum neutron dose, i.e. for a closed MLC, is ~0.04% of the target dose. The MMLC leaf width at iso center is 3.2 mm; the lateral penumbra in air is 0.6 mm. **Conclusion:** In beam-lines with a large SAD, such as our stereotactic beam-line, the use of the MMLC as aperture is feasible. The device can be positioned far away from the patient, which reduces the neutron dose to acceptable levels, while hardly compromising the lateral penumbra. Given a decrease in proton efficiency of a factor of 3, the MMLC could also be used for IMPT.

IMRT Verification and Quality Assurance I

TU-C-T-6E-01

Accurate IMRT Verification with Fluoroscopic EPIDs: A Generally Applicable Method Based On Direct Imaging of Cross-Talk Kernels

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Purpose: CCD camera-based electronic portal imaging devices (CEPIDs) are well suited for absolute dosimetric measurements and are applied routinely for IMRT verification in our institute. CEPID dosimetry is mainly hampered by cross-talk, which originates predominantly from optical photons reflected within the EPID structure. Previously, this cross-talk was corrected for based on specific assumptions. However, the sensitive cameras in our present CEPIDs allow for direct imaging of the low-amplitude, spatially extended cross-talk kernels. Thus complete, position dependent characterization of the cross-talk has become feasible. Here, we investigate the accuracy with which portal dose images (PDIs) can be derived from CEPID images (EPIs), using this cross-talk characterization. **Method and Materials:** Cross-talk kernels were obtained from EPIs of 2x2 cm^2 'pencil' beams, centered on a 30-position grid covering the EPID sensitive area. In the experimental set-up and post-processing, care was taken to exclude contributions of low-magnitude long-range incident MeV-radiation to the kernels. By interpolation of the measured kernels, a high resolution kernel-database was generated. Using this database, PDIs can be derived from EPIs by iterative deconvolution of the cross-talk contribution. Absolute PDI calibration was based on EPIs and corresponding PDIs, obtained by scanning a linear diode array (LDA), for two reference fields. To test the accuracy of this method, we compared EPI-derived PDIs with LDA-based PDIs for a series of symmetric and asymmetric fields, including Alderson-phantom thorax and IMRT fields. **Results:** The measured cross-talk kernels were asymmetrical and position-dependent. PDIs derived from EPIs with these cross-talk kernels matched with LDA-based PDIs to within 1% (1 SD) for all investigated fields (including IMRT), both inside and outside the field penumbras. **Conclusion:** We have developed a generally applicable method to determine position-dependent cross-talk kernels via direct imaging. With these kernels, we can derive accurate PDIs from EPIs that are well-suited for dosimetric IMRT verification.

TU-C-T-6E-02

A Computational Algorithm for Independent Planar Dose Verification of IMRT

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Purpose: The purpose of this work is to develop a computational algorithm for independent planar dose verification of IMRT plans delivered with an MLC as part of the IMRT quality assurance procedure. **Method and Materials:** A pencil beam convolution method was adopted for the algorithm. The general scheme of the calculation consists of three parts. The first part calculates the delivered fluence in air based on the positions of the leaves and jaws specified in the RTP file. We employed a modified three-source model to obtain 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. In the second part, dose kernel in phantom was determined by fitting the convolution results with a series of square-field profiles. Thirdly, the mid-leaf and interleaf transmissions, rounded leaf end, and tongue-and-groove effects were considered to improve the accuracy of the algorithm. All of these effects were taken into account by semi-empirical methodology and the parameters were obtained by fits to measured data. To verify the accuracy of the algorithm, we compared the calculation results with the MapCHECK measurements. **Results:** The accuracy of the algorithm was verified by comparing the calculations with the MapCHECK measurements for several head-and-neck cases. The passing rate for most of the cases is above 95% with the 2% in absolute dose or 2-mm distance-to-agreement criteria. The agreement was better than the agreement between the results from a commercial planning system (Pinnacle^3, version 7.0g) and MapCHECK measurements for all the cases tested. **Conclusion:** An algorithm has been developed for independent planar dose verification of IMRT plans as part of the IMRT quality assurance procedure. Our methods could be implemented on other kinds of machines with minor modifications.

TU-C-T-6E-03

Adapting the Victoreen 7200(TM) Device as a Tool for Daily QA of the Helical Tomotherapy Hi-Art(TM) Unit

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Purpose: To provide a simple procedure for RTT staff performing daily QA of a Helical Tomotherapy Hi-Art Unit™ using a Victoreen 7200 ™ ion chamber device. **Method and Materials:** Intended for use on conventional linacs, the Victoreen 7200™ consists of a flat paddle containing 10 ion chambers embedded 5 mm deep and spanning a 20cm x 20 cm field size. There are 2 perpendicular linear arrays containing 5 chambers each with a common center chamber. The 10th chamber is located diagonally away from the center and may be covered with a stainless steel attenuator. Firmware permits entry of baseline values, temperature and pressure for measurement corrections, and computationally provides beam output, symmetry, flatness, and energy constancy information with only one exposure. By diagonal alignment of this device with the green lasers of the Hi-Art ™ Tomotherapy Unit, a single, fixed gantry angle (0) beam exposure of 30 seconds using a 5 cm jaw width provides radiation constancy information within established tolerances for daily QA. The device is covered with a 1 cm acrylic build up sheet and a 15 mm stainless attenuator is used for energy constancy. Measurements are made with the treatment couch lowered so the SSD to the top of acrylic sheet is 103.8 cm. The diagonal alignment permits monitoring of the 5 cm jaw width. With a built in RS232 port, this information is easily downloaded into software applications permitting QA analysis and tracking with pass/fail criteria. (Our information is downloaded into ARGUS™.) **Results:** Analysis of more than 20 data sets indicates reliable and reproducible device performance. The procedure is simple and information rich. **Conclusion:** The Victoreen 7200™ device is easily adapted to Helical Tomotherapy Daily QA. **Conflict of Interest:** A collaborative research relationship is currently being developed with TOMOTHERAPY, Inc.

TU-C-T-6E-04

Clinical Reference Dosimetry of a "Hi-Art II" Helical Tomotherapy Machine

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Purpose: To develop a procedure for calibrating "Hi-Art II" helical tomotherapy machines using TG-51 and analyze the uncertainties associated with minor departures from the TG-51 protocol. **Method and Materials:** Physical limitations of the tomotherapy unit (85cm SAD) restrict the user from performing a rigorous TG-51 calibration. The Radiological Physics Center determined the ionization ratio (IR) using a water phantom and Exradin A12 ion chamber for a 40cm x 5cm field (8.9^2 eq.sq.). The IR was converted to $\%dd(10)_x$ using a published relationship between $\%dd(10)_x$ and IR. The beam quality conversion factor, k_Q, was determined, P_{ion} was measured and P_{pol} was assumed to be unity. The ion chamber center electrode was placed at d_{max}, instead of the recommended 10cm depth. The output/min was calculated using TG-51 and verified using a newly designed TLD jig. **Results:** The measured IR indicates a beam energy slightly greater than that for a 4 MV x-ray beam. The reference calibration resulted in a dose rate of 882.7 cGy/min at d_{max} for a 40cm x 5cm field at 85cm SAD that was within 1% of the dose rate (890.6 cGy/min) set by the factory where 0.4% of the difference was due to ADCL calibration differences and an un-flattened beam. The TLD/ion-chamber dose ratio was 0.993 (std.dev.= 0.007). An analysis of uncertainties associated with measuring IR and conversion to $\%dd(10)_x$, use of a 40 x 5 cm^2 field instead of 10 x 10 cm^2 and calibration at d_{max} instead of 10 cm results in a possible increased uncertainty of 0.5% in the final reference calibration. We believe this to be negligible. **Conclusion:** A procedure was developed to calibrate "Hi-Art II" tomotherapy machines using TG-51 with a minimal increase in the uncertainty of the final calculated dose rate.

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TU-C-T-6E-05

Dosimetry Acccracy Of Delivery Of Gold Beam Data IMRT Plans On Similar Linear Accelerators With Same Vendor

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Purpose: Under certain circumstances, IMRT patients need to be transferred from one Linac to another. Since a same set of commercial Gold Beam Data (GBD) have been used to model the treatment planning systems for multiple similar types of Linacs at our centers, the dosimetric accuracy needs to be investigated to determine the necessity of replanning when the treatment of an IMRT patient is moved from one machine to another. In this study, we investigated the dosimetric accuracies of IMRT plans delivered on different similar Varian accelerators. **Method and Materials:** In our institution, GBD has been used to model the Eclipse™ treatment planning systems for certain types of Varian machines (23 EX). IMRT treatments were planned using the Eclipse™ systems with 6 and 10 MV photon beams for different anatomical sites. Corresponding QA plans were also generated. The QA plans were used in the validation measurements, and the same measurements (same plans, same MU & dMLC files and phantom) were repeated on five of those Linacs. The measurements were performed using both ion chambers and films. **Results:** For plans using 6 MV photon beams, the mean ratios of planned to measured dose on the five machines for breast, prostate, tonsil, pelvis and brain plans were 0.984(SD0.0078), 0.998(SD0.0029), 0.979(SD0.0121), 1.006(SD0.0132) and 1.012(SD0.0054), respectively. For plans using 10 MV photon beams, the mean ratios of planned to measured dose on two of the machines for breast and pelvis were 0.979(SD0.00) and 0.949(SD0.0042), respectively. In the film analysis, a good agreement was found between films and plan isodoses on a coronal plane (for high dose gradients $\pm$ 2 mm and low dose gradients $\pm$ 4 mm). **Conclusion:** This study demonstrated that the IMRT patients could be transferred from one machine to another similar Varian machine with same energy without replanning.

TU-C-T-6E-06

First Clinical Experience with Pre-Treatment and in Vivo IMRT Verification Using EPID Dosimetry

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Purpose: The aim of this study was to verify the first IMRT prostate plans made in our clinic with a newly commissioned treatment planning system (TPS, Pinnacle 7.4f) using an amorphous silicon electronic portal imaging device (a-Si EPID, Elekta iViewGT), both pre-treatment and *in vivo*. **Method and Materials:** For pre-treatment verification, the plans of 8 patients were re-calculated on a polystyrene slab phantom. An in-house developed back-projection algorithm was used to estimate the dose distribution at the phantom/patient isocentric mid-plane (perpendicular to the beam-axis) with the EPID. Each plan was also validated at the isocentre with ionization chamber measurements. Separate fields were measured with film and EPID, with gantry angle =0°. The *in vivo* mid-plane dose was estimated with the EPID for the first 3 fractions and weekly thereafter. γ–evaluation was used to assess 2D dose distributions with criteria of 3% dose difference (of maximum dose) and 3mm distance-to-agreement. The evaluated area included all points within the 20% isodose line of each EPID field. Anatomy changes for *in vivo* measurements were assessed using cone-beam CT acquired prior to each verified fraction. **Results:** For pre-treatment verification, the dose distributions of EPID vs. plan and EPID vs. film agreed within 3% or 3mm for 99.2% and 100% of points, respectively. The average ratio of the measured and planned isocentre dose was 0.987 $\pm$0.003(SD) for ionization chamber and 0.997 $\pm$0.009(SD) for EPID. For the *in vivo* fields, 96.7% of dose points were in agreement. Examples of discrepancies were due to variation in gas pockets during treatment and problems calculating the dose distribution in a small area of overlapping segments (1cm2). **Conclusion:** These results show that an a-Si EPID can be used to accurately verify IMRT prostate treatments in the mid-plane of the phantom or patient, both pre-treatment and *in vivo*.

TU-C-T-6E-07

Monte Carlo Investigation of Dosimetric Differences Between SMLC and DMLC IMRT Delivery Techniques in Heterogeneous Media

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Purpose: To investigate dosimetric differences between SMLC and DMLC IMRT delivery techniques in heterogeneous media using MC. We hypothesize that subtle differences in the energy spectra between SMLC and DMLC, which may not be detected in water, will be accentuated in inhomogeneous, patient-like tissues. With the ability to account for MLC design details and perform accurate transport in heterogeneous media, MC provides a powerful means to evaluate IMRT delivery methods and may be useful as a tool for IMRT QA. **Method and Materials:** The BEAMnrc code was used to simulate patient independent components of a Varian 21EX linac. The resultant Phase space file was then used as input for the DPM MC code which simulates the jaws, 120-leaf MLC geometry, and the patient or phantom. Transport through the jaws and MLC is accomplished using multiple scatter photon transport. Sampling algorithms have been developed for SMLC and DMLC by randomly sampling leaf segments based on the MU index. Accuracy of the simulations was assessed in a homogeneous media when compared to measurements in a solid water phantom. To assess the impact of MLC design and delivery technique in heterogeneous media, dose was calculated in a phantom consisting of material slabs ranging in density from lung to cortical bone using SMLC and DMLC leaf sequences. **Results:** Excellent agreement was seen between the Monte Carlo models for SMLC and DMLC sequencing when compared to the respective film measurements in homogenous media. Significant differences, up to 10%, were seen between the delivery techniques in lung equivalent media when calculated in heterogeneous slab geometry. **Conclusion:** This study provides evidence that heterogeneous tissue may exacerbate energy differences between SMLC and DMLC delivery methods. Such differences may be clinically important considering that they will not be detected during QA which is typically conducted using homogeneous phantoms.

TU-C-T-6E-08

Statistical Analysis of IMRT Treatment Verification Films

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Purpose: To compare the delivery of an intensity modulated radiation therapy (IMRT) treatment with the computer generated plan and to quantify this comparison using statistical techniques. **Method and Materials:** Comprehensive quality assurance is performed for every patient who undergoes an IMRT treatment. Part of this treatment planning and delivery check involves irradiating a set of Gafchromic® EBT and/or Kodak EDR2 radiographic films. These images are converted to absolute dose and compared with the computer predicted dose maps. Two different implementations of principal component analysis (PCA) are employed for these comparisons. One system consists of creating a scatter plot of lexicographical representations of the irradiated film and the planar dose map (PDM) predicted by the treatment planning system, and the other utilizes the eigenvectors of the covariance matrix of the PDM and film for computing the PCA. **Results:** The results and merits of the mathematical PCA and geometrical variance techniques are compared with the pure image subtraction and distance-to-agreement (DTA) methods. The two statistical methods provide a more complete representation of potential radiation intensity delivery errors than the two latter ones. For some cases, small streaks of high-level radiation that appeared in the films but not on the plans were more pronounced in the statistically produced images. On other cases, the fact that the subtraction and the PCA methods both indicated the same unplanned hot spots provided more assurance on the verification quality. **Conclusion:** All these approaches to IMRT image evaluations -namely the two statistical, image subtraction, and DTA methods- are sufficiently robust to decipher most treatment delivery errors. However, since each method performs the image analysis differently, combining all these techniques is more powerful in detecting discrepancies in treatment delivery versus the IMRT plans and guarantees discovering any anomalies in radiation delivery in almost all the cases.

TU-C-T-6E-09

The DAVID System – a Device for In-Vivo Verification of IMRT and Conformal Irradiation Techniques

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Purpose: While dosimetric plan verification ensures consistency between planned and measured dose distributions in the pretreatment phase, a daily *in-vivo* verification of the beam profiles by a radiation detector positioned at the entrance side of the patient has not been clinically available so far.
In this work we present the DAVID system which is able to perform a daily *in-vivo* verification of IMRT beams in front of the patient during the treatment. **Method and Materials:** The DAVID system is a flat, translucent multi-wire ionization chamber. 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 measurement signal of each detection wire is directly proportional to the opening of the leaf pair. Therefore the number of measurement channels equals the number of leaf pairs. 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. **Results:** The error detection capability for a 1 cm x 1 cm field is a leaf position error of less than 0.5 mm. The inherent limit due to electronic noise of the chamber is 1mm for a 20 cm x 20 cm field (all values related to the isocenter). **Conclusion:** Clinical examples demonstrate that the DAVID system is a relevant tool to improve the reliability of IMRT treatments. 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. **Conflict of Interest:** This work was performed in collaboration with PTW-Freiburg Dr. Pychlau GmbH, Freiburg, Germany.

TU-C-T-6E-10

Using Fluence-Separation to Account for Energy Spectra Dependence in Computing Dosimetric ASi EPID Images for IMRT Fields

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Purpose: Dosimetric aSi EPID images are typically computed using a convolution of energy fluence with an invariant energy deposition kernel. However, Monte Carlo (MC) studies show a strong dependence of the EPID imager response to energy spectra, which, for highly modulated IMRT fields, severely affects the dosimetric accuracy. To account for this, a method is developed that accounts for the radial-dependence of the energy deposition kernel and considers open field and MLC hardened components of the energy fluence. **Method and Materials:** Dosimetric EPID images are created by convolving energy fluence with a radially dependent kernel. The energy fluence at the EPID surface was determined by extracting the terma in water from Pinnacle. For each fluence element, the energy fluence (Ψ) was divided into two parts --- open field energy fluence Ψ_o, and MLC blocked field energy fluence Ψ_c. Ψ_o and Ψ_c were convolved separately with their respective energy-deposition kernels and the results summed. Calculations were compared with measurements for, 3×3-20×20 cm^2 fields, rectangular fields, a 10×10 cm^2 field centered at (5cm,-5cm)), 3×3-12×12 cm^2 MLC-blocked fields, and dynamic MLC sliding window fields which generate 10×10 cm^2 fields with window gaps ranging from 1- to 50-mm .Test cases were compared utilizing profiles and using gamma-analysis for pixels receiving doses >50 % D_{max}. A 3 mm, 3% criteria was used in the gamma analysis. **Results:** Measured and computed dose profiles agreed for both in-field and out-of-field regions. For the open field test cases, all points evaluated had $\gamma < 1.0$. For MLC blocked fields ≤10×10 cm^2, >98.5% of points had $\gamma < 1.0$ Over 98% of points passed the gamma-test for most sliding window field. **Conclusion:** Accurate aSi dosimetric EPID images can be computed when energy spectra hardening is accounted for during the image calculation. **Conflict of Interest:** This work supported in-part by Varian Medical Systems.

Workshop Room 608

Ultrasound QC Workshop

TU-C-W-608-01

Ultrasound QC Workshop

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This workshop will provide attendees an opportunity to observe ultrasound scanner operations and quality assurance procedures. A portable ultrasound unit and various ultrasound QC phantoms will be provided and used to demonstrate the QC procedures. A set of QC test procedures described in AAPM Ultrasound Task Group 1 Report (Medical Physics 1998;Vol 25: 1385-1406) will be presented, including display monitor fidelity, image uniformity, depth of visualization, horizontal and vertical distance accuracy, axial and lateral resolution, slice thickness, dead zone measurement. Demonstrations of test procedures and equipment will be performed by the instructors and industry representatives.

Educational Objectives:
1. To learn the effect of parameter settings on various aspects of ultrasound imaging.
2. To observe the ultrasound quality control test procedures for real-time B-mode units.
3. To become acquainted with various ultrasound QC phantoms.

Imaging Scientific Session Room 611

Cone-Beam CT

TU-D-I-611-01

A General Method for Micro CT System Calibration with Phantom Scan

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Purpose: System calibration of a micro CT scanner for anatomic imaging of small animals. **Method and Materials:** A phantom was constructed with lead ball bearings (200 μm in diameter) and scanned with a micro CT scanner designed and built in our laboratory. A general mathematical algorithm was developed to locate the X-ray focal spot and measure the source to detector distance (SID) and the azimuthal rotation of the detector with information acquired from the projection image of the phantom. A wire phantom (0.070mm Ni-Cd) was scanned to calibrate the angle measurement of the stepping motor which drives the rotating stage of the scanner, and also to measure the source to iso-center distance (SIC). An array of different objects was scanned and reconstructed with these calibrated parameters to evaluate the calibration result. **Results:** With the calibration procedure described, critical system parameters required for cone beam reconstruction including SIC, SID, x-ray focal spot location, detector rotation angle, and stage rotation angle were measured with high precision. Subsequent phantom testing demonstrated the accuracy of this calibration method by qualitative artifact assessment, and spatial resolution metrics (MTF) also demonstrated excellent performance. **Conclusion:** A simple but precise method for system calibration of a cone beam micro CT system using flat panel detector was developed. This method is likely useful for CT systems across different scales (from micro CT to human CT).

TU-D-I-611-02

Volumetric Cone Beam Reconstruction Engines for 4D Image Guidance

J Maltz*, B Gangadharan, D Hristov, M Svatos, Siemens Medical Solutions USA, Concord, CA, Siemens Medical Solutions, Concord, CA, Siemens Medical Solutions USA, Inc. -, Concord, CA

Purpose: Limited angle tomography (LAT) may be used to rapidly reconstruct longitudinal slice images from cone beam datasets. These images are useful for image guidance in radiotherapy applications. By sampling a limited angular range (AR) imaging time is reduced, particularly in prospectively gated studies. We compare the LAT

performance, as a function of AR, of the standard FDK algorithm and the simultaneous algebraic reconstruction technique (SART). We propose an imaging protocol to minimize dose and imaging time, while providing image guidance. **Method and Materials:** We employ LAT reconstruction (LATview) to produce high contrast images of a target tumor in the presence of large amounts of overlying and underlying anatomy. The performance of the SART and FDK s compared for ARs of 15-60 degrees. **Results:** We demonstrate using a 4D clinical thorax dataset that a lung tumor may be well delineated from within the ribcage along longitudinal planes utilizing as few as 8 projections over 15 degrees of arc using FDK. Assuming an average patient respiration rate of 0.3Hz, gated imaging is completed within 24 seconds. This constitutes an 8-fold reduction in imaging time when compared to a full AR tomographic acquisition involving 60 projections over 200 degrees. **Conclusion:** LATview offers significant speed advantages over full angular sampling for 4D studies. It is also more versatile than techniques of digital tomosynthesis as it is able to simultaneously generate multiple image planes of the target volume. Both FDK and SART appear useful for image guidance. Although the SART images subjectively provide more detail, this detail may reduce the tumor-background contrast (TBC). As a result, TBC is higher for FDK for the lowest AR (15 degree) acquisitions, while SART performs better in terms of TBC for ranges of more than 30 degrees. **Conflict of Interest:** Supported by Siemens Medical Solutions USA, Inc.

TU-D-I-611-03

Cone-Beam Image Reconstruction for Circular-Arc Trajectories Via Shift-Invariant Horizontal and Non-Horizontal Filtering

B Nett*, T Zhuang, G Chen, Dept. of Medical Physics, University of Wisconsin, Madison, WI

Purpose: To propose and validate a novel shift-invariant filtered backprojection (FBP) type cone-beam reconstruction algorithm for circular-arc scanning trajectories. This algorithm has been proposed to address two shortcomings in the FDK algorithm; namely, limited visibility of low contrast objects in the off-center planes and the inability to provide clinically acceptable reconstruction when the scanning path is shorter than the short-scan condition. **Method and Materials:** Based upon the application of an exact cone-beam reconstruction algorithm to the case of a circular trajectory, which does not fulfill the Tuy data sufficiency condition, a new algorithm has been developed. The new algorithm differs from the heuristic FDK algorithm in that multiple sets of filtered data are utilized in reconstructing the value of a single image point. The new algorithm introduces non-horizontal filtering which is not achievable by heuristic extension fan-beam FBP reconstruction. In this manner more of the cone-beam data is utilized in the filtering operation. The new algorithm also enables region-of-interest (ROI) reconstruction in a super-short scan mode (less than the short-scan angular range). **Results:** Computer simulations were performed using analytical data generated for a standard low contrast phantom. The new algorithm provided improved visualization of structures that lie in off-center planes when compared with the FDK algorithm. In addition simulations were performed to validate the ROI reconstruction using a super-short scan mode. **Conclusion:** The circular-arc scanning trajectories are used frequently in cone-beam CT on interventional C-Arm systems, micro CT systems and cone-beam CT guided radiation therapy. A new shift-invariant FBP type cone-beam reconstruction algorithm has been proposed and validated for this common source trajectory. In comparison with the standard FDK algorithm the new algorithm provides improved visualization of structures that lie in off-center planes, and it enables a super-short scan mode for ROI reconstruction.

TU-D-I-611-04

Intensity-Modulated Cone-Beam CT for Patient-Specific Distribution of SNR

S Graham*[1], J Siewerdsen[2], H Keller[1], D Moseley[1], D Jaffray[1], (1) Princess Margaret Hospital, Toronto, Ontario, CA, (2) University Health Network, Toronto, ON, CA

Purpose: In order to maximize task-specific image quality for cone-beam CT systems used in image-guided radiation therapy, investigations are being performed to establish compensating filters capable of modulating the fluence pattern applied during image acquisition for patient and task-specific distributions of signal-to-noise (SNR). The repetitive image-guidance problem allows optimization at the patient-specific level by making use of previously acquired patient images to define regions of interest (ROIs) or a distribution of desired image quality. These ROIs or distributions can be employed to generate intensity modulated fluence patterns for application during acquisition. **Method and Materials:** Investigations into the development of compensation systems for creating SNR patterns are performed through simulations and experimental studies on a bench-top cone-beam CT system (Varian 4030A flat-panel, Rad-92 X-ray tube, motorized rotation stage). Numerical simulations (Matlab™) on a Shepp-Logan phantom are employed to generate binarized masks according to defined ROIs in the object space. Modulation of noise containing sinogram data followed by filtered backprojection permits SNR distribution recovery. Experimental studies using modulating filters were performed to evaluate the robustness of the technique in realistic systems. **Results:** Simulations into the feasibility of tailor made SNR patterns created by advanced compensation schemes show that it is possible to design a gantry angle dependent compensation system capable of achieving desired SNR in defined ROIs. Experimental results reveal the ability to modify SNR across images providing specific regions with improved SNR while reducing local and/or integral dose. **Conclusion:** Cone-beam CT compensators have been explored to provide modulated, patient-specific, fluence patterns optimizing the distribution of SNR within the resulting image. This technique opens the opportunity to optimize image quality in the most clinically relevant regions of an image, while reducing dose to the patient by reducing the fluence intensity outside defined ROIs.

TU-D-I-611-05

Monte Carlo Investigation of Scatter Contribution to Kilovoltage Cone-Beam Computed Tomography Images

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Purpose: In this work, we evaluate the scatter radiation present in projection images produced by kilovoltage (kV) cone-beam computed tomography (CBCT) using Monte Carlo (MC) calculations. We also demonstrate that MC simulations can be used to reduce scatter in kV CBCT reconstructed images. **Method and Materials:** All images were acquired using a kV CBCT bench-top system composed of an x-ray tube, a rotation stage and a CsI flat-panel imager. The EGSnrc MC code was used to fully model the flat-panel imager and the x-ray source for energies of 80, 100, and 120 kVp. The x-ray source model was validated using first and second half-value layer (HVL) and profile measurements. MC simulations and measured images were obtained for a cylindrical water phantom and for the head of the anthropomorphic Rando phantom. A modified version of the DOSXYZnrc program was used to score phase space files with identified scattered and non-scattered particles after the phantoms. The cone angle and the source-to-detector distance (SDD) were varied during the simulations to determine their effect on scatter radiation in projection images. MC predictions of the scatter distribution were subtracted from the CBCT projection images prior to the reconstruction to improve the reconstructed image quality. **Results:** The simulated and measured first and second HVL agree within 2% except for the 80 kVp beam where the agreement is within 9%. The measured and simulated profiles agree within 4%. Simulated and measured projection images are in good agreement. Decreasing the cone angle and increasing the SDD decrease the amount of scatter. On the other hand, the phantom geometry has little effect on the scatter radiation distribution. **Conclusion:** MC simulations were used to characterize the scatter radiation from different geometries. It was shown that it is possible to use MC simulations to reduce the scatter in the reconstructed image.

TU-D-I-611-06

A Direct, Empirical Method for X-Ray Scatter Correction in Digital Radiography and Cone-Beam CT

J Siewerdsen*[1, 2], B Bakhtiar[1], D Moseley[1], S Richard[2], H Keller[1], M Daly[1], D Jaffray[1, 2], (1) Ontario Cancer Institute, Princess Margaret Hospital, University Health Network, Toronto, ON, Canada, (2) Department of Medical Biophysics, University of Toronto, Toronto, ON, Canada

Purpose: X-ray scatter poses a severe physical limitation to image quality in cone-beam CT (CBCT), resulting in contrast reduction, image artifacts, and lack of CT number accuracy. We report and demonstrate the

performance of a novel scatter correction method in which scatter fluence is estimated directly in each projection from pixel values at the edge of the detector behind the collimator leaves. **Method and Materials:** The algorithm operates on the assumption that signal behind the collimator leaves is attributable to x-ray scatter. The 2D scatter fluence is estimated by interpolating between pixel values measured along the top and bottom edges of the detector behind the collimator leaves. The resulting scatter fluence is subtracted from each projection to yield primary-only images for CBCT reconstruction. Performance was investigated in phantom experiments on an experimental CBCT benchtop, and the effect on image quality was demonstrated in patient images (head, chest, and pelvis sites) obtained on a preclinical system for CBCT-guided radiation therapy.
Results: The algorithm provides significant reduction in scatter artifacts without compromise in contrast-to-noise ratio (CNR) – e.g., Head: cupping reduced from 10% to 2%, while breast-to-water CNR improved from 5.2% to 7.8%; Body: cupping reduced from 42% to 26% without change in CNR. Patient images demonstrate increased uniformity, accuracy, and contrast, with slightly increased noise (net increase in CNR) in all of the sites investigated. Qualitative evaluation illustrates that soft-tissue structures that are otherwise undetectable are clearly delineated in scatter-corrected reconstructions. **Conclusion:** The algorithm provides a robust method for x-ray scatter fluence estimation and correction in CBCT. Operating from a single assumption without prior information, analytical modeling, or Monte Carlo, the technique is easily incorporated as a preprocessing step in CBCT reconstruction. Quantitative evaluation in phantoms and pre-clinical evaluation in patients demonstrates significant artifact reduction without degradation in CNR.

TU-D-I-611-07

A Scanning Sampled Measurement (SSM) Technique for Scatter Measurement and Correction in Cone Beam Breast CT

X Liu*, C Shaw, M Altunbas, T Wang, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: To implement and investigate a scanning sampled measurement (SSM) technique used to obtain sampled scatter measurement for scatter correction in cone beam breast CT. **Method and Materials:** Breast phantom or specimen is mounted on the rotating stage in a stationary gantry experimental cone beam CT system. A slightly tilted 2-D array of 1.2-mm diameter lead beads, with the beads 1 cm apart from each other, was placed between the object and x-ray source. A series of projection images were acquired as the phantom is rotated (1 degree per projection view) and the lead beads array shifted by 1.2-mm from one projection view to the next. Image signals in the lead bead shadow were used to obtain sampled scatter measurements which are then interpolated to form an estimated scatter distribution. The image data in the lead bead shadows are restored by interpolating image data from the two adjacent projection views to form complete (lead bead free) projection images. The estimated scatter distribution is then subtracted from the corresponding restored projection image to obtain the scatter corrected projection images. **Results:** Sampled scatter measurements were successfully made in each projection image and the accuracy of scatter measurements was verified with a larger beam blocker placed between the lead beads and x-ray source. The SPRs in the projection images of a breast phantom are found to range from 0.1 to 0.5. Using scatter distribution interpolated from scanning sampled measurements and restored projection image data, scatter correction was successfully performed on all projection images. The resulting scatter corrected projection image data resulted in more accurate reconstruction of the linear attenuation coefficients and reduced the cupping effects.

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TU-D-I-611-08

Cone Beam X-Ray Scatter Removal Via Image Frequency Modulation and Filtering

A Bani-Hashemi, E Blanz, J Maltz*, D Hristov, M Svatos, Siemens Medical Solutions, USA, Inc.

Purpose: To develop a rapid method of patient scatter removal from cone beam (CB) projection images that requires no scatter measurement, physical modeling or strong assumptions regarding the spatial smoothness of the scatter distribution. **Method and Materials:** A modulator grid is placed between the imaged distribution and the detector that differentially frequency modulates primary and scattered photons. When photons travel through the grid, photons that originate directly from the CB source are modulated by a higher frequency than scattered photons that have more proximal, diffusely distributed sources. We employ non-linear Fourier domain filtering to attenuate the contribution of scatter to the image spectrum. The theoretical validity of the method is verified using linear analysis of planar sources and its performance is evaluated using a simulator based on this analytical model.
Results: Simulation experiments with an ideal modulator indicate that even unrealistically large amounts of scatter are almost entirely removed by this method. The recovered images are devoid of major artifacts and exhibit an RMS error of 10%. **Conclusion:** A disadvantage of the technique is that it will always produce a filtered image having at best 0.41 of the maximum detector resolution when maximum scatter rejection is desired. This is not a major issue in most medical X-ray CB imaging applications using contemporary detector technology, especially since scatter often significantly reduces useful resolution. **Conflict of Interest:** Supported by Siemens Medical Solutions USA, Inc.

Imaging Symposium Room 609

Measuring the Clinical Impact of CAD on Screening Mammography

TU-D-I-609-01

Overview

R Nishikawa*, Univ Chicago, Chicago, IL

Laboratory experiments including observer studies suggest that CADe should be effective in improving the accuracy of mammography. However, the few clinical studies reported have not been as positive as the non-clinical studies have indicated. There are several possible explanations for this that will be discussed in this forum. These include (a) methodological problems making it difficult to measure any true improvement; (b) laboratory experiments are too different from actual clinical conditions (c) CADe is an effective clinical tool only under certain conditions. This symposium will discuss these issues.

TU-D-I-609-02

What to Expect When CAD Is Implemented Clinically

R Nishikawa*, Univ Chicago, Chicago, IL

I have developed a simple model to study the effects of computer-aided detection (CADe) on screening mammography. The model incorporates tumor growth rate, the sensitivity of radiologists and the CADe scheme, how effectively the radiologist uses the CADe output, and the interval cancer rate. The model shows that the additional cancers detected when the radiologists uses CADe depends on how many cancers the radiologist misses without the computer aid, how many of the missed cancers the computer can detect, and what fraction of the computer detected missed cancers the radiologist will correctly recognize as a missed cancer. I also modeled the effect of CADe on radiologist false-detection rate. Unless the computer can preferentially detect cancers over benign lesions, the increase in the number of cancers detected when using CADe will be the same as the increase in the number of women recalled (the vast majority of which will be false positives). This does not imply that CADe has no net affect. On the contrary, an equal increase in the cancer detection rate and the recall rate is consistent with radiologists operating on a higher ROC curve implying that CADe is improving the radiologists' performance. However, even if CADe was able to help radiologists reduce their miss rate by 50%, there will be only a 10% increase in the cancer detection rate before and after implementation of CADe. This increased is difficult to detect in practice because of the variable growth rate of tumors. The number of cancers present in a screened population will change year by year so that this variation can mask the actual increase in the cancer rate when CADe is implemented. However, the size of the cancers detected when using CADe is smaller than those detected by the radiologist when not using CADe.

Educational Objectives:
1. Understand the factors affecting the clinical effectiveness of computer-aided detection
2. Understand some of the difficulties of measuring the clinical effectiveness of computer-aided detection

Financial Disclosure
RM Nishikawa is a shareholder in R2 Technology, Inc. (Sunnyvale, CA). He also receives research funding and royalties from R2 Technology.

TU-D-I-609-03

Computer-Aided Detection (CAD) in the Laboratory and the Clinical Environment

D Gur*, Univ Pittsburgh, Pittsburgh, PA

Computer-Aided Detection (CAD) is intended to be used in a specific way and several studies have shown that when it is used appropriately improvements in performance can be realized. The effect seems to be much more noticeable in the laboratory than in the clinic. Data ascertained in both environments clearly suggest that the measurement methodology is extremely important as is the actual use of CAD as a part of the clinical workflow. Our observations suggest the following: 1) regardless of the actual improvement (or not) in accuracy, CAD is an important tool; 2) most radiologist do not use it in the clinical environment as originally intended; 3) comparison of sequential viewing "without" followed by "with" CAD may not be the appropriate/optimal way to analyze accuracy improvements; 4) change in detection rates are expected to be low and temporary, while change in average size (or stage) are expected to be small and persistent; 5) performance of the CAD alone does affect observer performance; 6) reliance on CAD in the area of micro-calcifications may result in an increase in biopsy rates; 7) there is a significant difference in the performance of current CAD systems in regards to the detection of micro-calcifications and masses, and this difference results in a significant difference in the level of reliance on CAD results with respect to the two abnormalities. These observations and the supporting experimental data will be shown and discussed.

Educational Objectives:
1. Understanding the difficulty in measuring performance changes with the incorporation of CAD technology into the clinical environment.
2. Understanding the importance of study design in measuring the impact of CAD technology.
3. Understanding the magnitude of the "human" factor in observer performance studies.

TU-D-I-609-04

Effect of Reader Variability On Improvements in Breast Cancer Detection Rates

Y Jiang*[1], D Miglioretti[2], C Metz[1], R Schmidt[1], (1) University of Chicago, Chicago, IL, (2) Group Health Cooperative, Seattle, WA

Previous investigations have demonstrated variability among radiologists in the interpretation of screening mammograms. This presentation will discuss the extent of this variability and its effect on clinical trials that compare the conventional screening-film mammography and new technologies such as full-field digital mammography (FFDM) and computer-aided detection (CADe). We will present data on breast cancer detection rates at the conventional screen-film mammography of over 500 practicing community radiologists in the US. By postulating a large improvement in the cancer detection rate that would be achieved with a hypothetical new technology, we predicted the cancer detection rate that would be observed in a hypothetical clinical trial comparing the new technology and the conventional screen-film mammography. Despite a large postulated improvement in the cancer detection rate, it is difficult for clinical trials to demonstrate this improvement. Variability among radiologists in the observed cancer detection rates is an important cause for this difficulty. Clinical trials need to include large samples of radiologists in addition to large samples of patients to achieve sufficient statistical power to detect an improvement in the breast cancer detection rate in screening mammography. FFDM and CADe clinical trials, many of which appear to lack statistical power, will be discussed.

Educational Objectives:
1. To understand the sources and extent of variability in radiologists' breast cancer detection rates in screening mammography.
2. To understand the impact of reader variability on clinical trials that compare imaging technologies in screening mammography.
3. To understand the need to sample a large number of radiologists in addition to sampling a large number of patients to demonstrate an improvement in breast cancer detection rate in screening mammography.
4. Financial Disclosure: C Metz and R Schmidt are shareholders of R2 Technology, Inc.

Joint Imaging/Therapy Scientific Session Room 6C
4D Modeling and Margin Assessment I

TU-D-J-6C-01

A Comparison Between Amplitude Sorting and Phase Sorting Using External Respiratory Measurements for 4D CT

W Lu*, P Parikh, J Bradley, D Low, Washington University School of Medicine, St. Louis, MO

Purpose: To compare amplitude sorting and phase sorting techniques using external respiratory measurements for 4D-CT for patients undergoing quiet breathing. **Method and Materials:** We have developed a 4D CT technique for mapping respiratory motion in radiotherapy treatment planning. A 16-slice CT scanner was operated in ciné mode to acquire 25 scans consecutively at each couch position. The scans were sorted into 12 respiratory-windows based on the amplitude and direction (inhalation or exhalation), and on the phase (0-360°) of a synchronized external respiratory measurement. An air content measure (the amount of air in a 16-slice CT segment, used as a surrogate for internal motion) was correlated to the respiratory amplitude and phase throughout the lung. Images reconstructed based on the two sorting techniques were displayed for a qualitative comparison. Also, the variations in the amplitude of the respiratory measurement during the entire scan session were compared using 8, 12, 24, and 48 respiratory windows. **Results:** The air content showed a higher correlation with the respiratory amplitude than with the respiratory phase for most cases. Images reconstructed based on the amplitude sorting technique displayed fewer artifacts, especially at the lung-diaphragm boundaries, than images reconstructed based on the phase sorting technique. The variations in the respiratory amplitude were much smaller with amplitude sorting than those with phase sorting. These variations decreased significantly with finer amplitude respiratory windows while showed insignificant changes with finer phase respiratory windows. **Conclusion:** The amplitude sorting was generally better than phase sorting, especially for patients whose breathing was less reproducible. The use of finer respiratory windows did not improve the consistency for phase sorting. **Keywords:** 4-D CT, respiratory sorting, motion, radiotherapy

TU-D-J-6C-02

Radiation Dose Reduction in 4D Computed Tomography

T Li*, E Schreibmann, B Thorndyke, L Xing, Stanford University School of Medicine, Stanford, CA

Purpose: 4D CT is useful clinically for detailed abdominal and thoracic imaging over the course of the respiratory cycle. However, it usually delivers 10~15 times more radiation dose to the patient as compared to the standard 3D CT, since multiple scans at each couch position are required to obtain the temporal information. In this work we propose a method to obtain high quality 4D CT with low tube current, hence reducing the radiation exposure of patients. **Method and Materials:** The improvement of the signal-to-noise ratio (SNR) of the CT image at a given phase was achieved by superposing the imaging information from other phases with the use of a deformable image registration model. To further reduce the statistical noise caused by low tube current, we developed a novel 4D penalized weighted least square (4D-PWLS) method to smooth the data spatially and temporally. The method was validated by motion-phantom and patient studies using a GE Discovery-ST PET/CT scanner. A Varian RPM respiratory gating system was used to track the motion and to facilitate the phase binning of the 4D CT data. **Results:** We calculated the SNRs for both studies. The average SNR of 10 mA phantom images increased by more than three-fold from 0.051 to 0.165 after the proposed 4D-PWLS processing, without noticeable resolution loss. The patient images acquired at 90mA showed an increase from 2.204 to 4.558 for the end-inspiration phase, and from 1.741 to 3.862 for the end-expiration phase, respectively. By examining the subtraction images before and after processing, good edge preservation was also observed in the patient study. **Conclusion:** By appropriately utilizing the temporal information in 4D-CT, the proposed method effectively suppresses the noise while preserving the

resolution. The technique provides a useful way to reduce the patient dose during 4D CT and is thus valuable for 4D-radiotherapy.

TU-D-J-6C-03

Image Segmentation in 4D CT Based On a Deformable Image Registration Model

L Xing*, E Schreibmann, Y Yang, A Boyer, T Li
Stanford University School of Medicine, Stanford, CA

Purpose: While 4D CT provides a powerful tool to study the anatomy change caused by respiration, a hurdle in fully realizing its potentials is how to segment the involved organs efficiently for all breathing phases. Here we investigate a strategy of using deformable image registration for mapping the contours delineated at a known phase to all other phases of the 4D CT images. **Method and Materials:** 4D CT image sets for four patients (one esophageal and three lung patients) were acquired by using a GE LightSpeed-QX/I scanner. Ten phase bins were used in the data acquisition. The involved organs were delineated by a physician on the 3D image sets corresponding to the inhale phase point. The images at different phases were registered using a BSpline deformable model implemented in the VTK/ITK platform. The contour points on the inhale phase were automatically mapped to the corresponding points on the images of other phases following the mapping relation established by the deformable model. The performance of the auto-segmentation tool was evaluated by comparing directly with the contours outlined by the physician on selected phases. **Results:** The deformable model was capable of accommodating significant variability of structures over time and across different individuals. In all patients, the mean measured error was 1mm for clearly differentiated organs such as the lungs, and 2 mm for medium-sized organs like heart. A maximum error of 4 mm was observed locally for noisy or binning-artifact degraded voxels. Additionally, the method was used to deduce tumor path at any phase, permitting close tailoring of the margins of the tumor targets in the presence of respiration. **Conclusion:** Contour evolution in 4D images can be easily defined and tracked using a BSpline deformable model, with no user interaction required. The method provides millimeter-accuracy while eliminating the labor-intensive segmentation procedure.

TU-D-J-6C-04

Assessing Margins Using Known Tumor Motion Trajectory and a Stochastic Convolution/superposition Algorithm

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Purpose: To incorporate the effect of tumor motion in routine dose calculations for conventional and IMRT treatment planning so that tumor margins can be optimized for individual patients based on their respective motion waveforms. **Method and Materials:** We employed the Monte Carlo Superposition method, which uses random sampling of beams, field segments, photon energy and direction, interaction points and kernel rays from appropriate probability distributions. In this work, the isocenter is also randomly sampled from the motion-time waveform of the patient's tumor. To verify the method, we performed film measurements on IMRT phantoms placed on a platform that moves sinusoidally in the left-right or superior-inferior direction with amplitude of 2-cm. For a test clinical case, a hepatic tumor case was created on a humanoid phantom using the Pinnacle^3 IMRT system. The optimized plan was re-calculated using MC-superposition dose engine using a motion waveform representative of typical respiratory induced motion. **Results:** Film measurements averaged over 10 fractions agreed with MC superposition with motion calculations (infinite fraction) within 1mm in isodose lines for both static and 2-cm sinusoidal motion cases. In the test IMRT liver case with realistic breathing waveform, the isodose lines are seen to shift in the superior direction. Slight underdosing of the GTV and significant underdosing of the PTV can be seen on the inferior side of the tumor, indicating that the 1cm margin on the GTV was not adequate to cover the tumor on the inferior border. Conversely, the margin was found to be too large on the superior tumor border, suggesting the need to reassign the margins and create a new plan. **Conclusion:** Our method provides a way for the clinicians to make informed decisions about margins required to cover the tumor based on actual motion waveforms of the patient's tumor.

TU-D-J-6C-05

Investigation of the Actually Delivered Patient Dose in Lung IMRT Treatment Based On Deformable Registration of 4D CT Data and Monte Carlo Simulations

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Purpose: To accurately calculate the difference between prescribed and delivered dose caused by respiratory motion and artifacts in free breathing helical CT (fbCT) for lung IMRT treatments, and to estimate the impact of this difference in clinical outcome. **Method and Materials:** Ten cases were studied. For all patients, fbCT and 4DCT reconstructed at 10 phases of the respiratory cycle were available. Patients were selected to have a wide range of tumor motion, size, and position. CORVUS was used to make two IMRT plans calculated on the fbCT for GTV (volume determined on fbCT) and ITV (volume determined by 4DCT) targets respectively. The prescribed dose was 60Gy. The fluence maps and beam setup parameters of the IMRT plans were used by the Monte Carlo dose calculation engine MCSIM for absolute dose calculation on free breathing and 4DCT data. CT deformable registration between the breathing phases was performed and the composite dose over the whole breathing cycle was calculated for the GTV, CTV and lungs. EUD and TCP/NTCP values were determined for the composite dose over the whole breathing cycle based on both plans. **Results:** For a patient with 4 cm peak to peak tumor movement, a planned CTV EUD of 58 Gy was reduced to 54Gy and 33Gy respectively for the composite 4D dose distribution of ITV and GTV plans. 3-year control estimates for this patient, assuming that 3-year local control after 60Gy in the GTV is 30%, were reduced to 29% and 23% for the ITV and the free breathing plans respectively.
Conclusion: With the advent of 4DCT, CT data deformable registration and Monte Carlo dose calculations, it is feasible to accurately calculate in retrospect the actually delivered dose and compare it with what historically was assumed to be delivered.

TU-D-J-6C-06

3D Respiratory Motion Estimation From Slowly Rotating 2D-Xray Projection Views

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Purpose: To more directly model changes in patient configuration due to respiratory motion during gantry rotation for "4D" cone-beam CT (CBCT). **Method and Materials:** The process takes advantage of the similarity between the patient at treatment and their model from a prior (planning) CT scan. A reference thorax volume is obtained from a conventional fast CT scanner under breath-hold conditions. At treatment, a sequence of projection views of the same patient is acquired using a slowly rotating cone-beam system, which takes 1 minute for a full rotation. Breathing motion over the entire acquisition period is estimated by deforming the reference volume through time to best match the measured projection views. A B-spline based motion model is used to describe free breathing motion. Optimized parameters of this model (by minimizing a regularized square error cost function) determine the motion of each point of the object at any time within the scanning period. Performance of this approach was evaluated by simulation, in which a 128x128x40 reference thorax volume and a 3D cone-beam geometry were used to generate 12 projection views of one breathing cycle. **Results:** Results showed good agreement between the estimated and true motion. A 30-degree angular rotation during one breathing cycle (5 seconds) yielded a mean absolute estimation error (MAE) of 0.7 mm (maximum 2.1mm). A 360-degree angular rotation yielded MAE of 0.4mm (maximum 1.3mm). **Conclusion:** It is feasible to estimate non-rigid motion from a sequence of slowly rotating projections. Improved accuracy with increased angular range indicates advantages of faster rotation or limited periodicity constraints.

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TU-D-J-6C-07

A Method for Acquiring PET Images Without Breathing Motion Artifacts

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Purpose: PET images typically require many minutes to acquire, so breathing motion can cause the tumor shape to be inaccurately reconstructed. Using a multislice PET/CT scanner to quantitatively acquire 4-dimensional computed tomography (4DCT) and gated PET, a breathing motion-artifact free PET image study can be generated achieving statistical precision as if the patient underwent breath-hold throughout the PET-scan procedure. **Method and Materials:** The motion of lung structures, including tumors, is mapped by 4DCT as a function of tidal volume using our novel 5-dimensional breathing motion model. The PET scan is performed using spirometry-measured tidal volume and the PET data is stored using list mode. The user selects the phase of breathing for which the PET image is to be reconstructed and the corresponding list-mode data is extracted to reconstruct an image. The gated-CT scans provide quantitative attenuation correction that is accurate with respect to breathing phase. This process is repeated for all breathing phases and using the trajectory maps the reconstructed images are deformably mapped to a reference-breathing phase. This process was tested using a computer-controlled phantom moving in a motion pattern mimicking breathing motion. Three target spheres (1cm, 2cm, 3cm diameters) filled with ^{11}C solution were embedded into a cylindrical phantom filled with ^{18}F solution to provide a series of relative target-to-background activities. **Results:** Without gating, the target spheres were deformed and the low target-to-background small-target image was lost in the background noise. These problems were alleviated when the images were mapped to a common motion "phase". **Conclusion:** The phantom data showed that motion artifacts can be quantitatively removed yielding a high statistics image dataset without compromising PET acquisition time or patient dose. This process will provide the radiation-oncology clinician with PET images having unrivaled spatial resolution and sensitivity for target definition in the thoracic and abdominal regions.

TU-D-J-6C-08

Enhancing 4D PET Through Retrospective Stacking

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Purpose: Four-dimensional (4D) PET presents challenges distinct from 4D CT owing to radiotracer dose limitations. A single-bed field-of-view (FOV) PET scan typically requires several minutes to acquire adequate data for reconstruction, necessarily spanning several respiratory cycles and smearing the radiotracer signal within a given lesion over an increased volume. Although prospective or retrospective gating captures the PET image at a single point in the respiratory cycle, restricting the data to events within the gating interval increases the signal-to-noise ratio (SNR). We propose a method, coined "retrospective stacking" (RS), to combine the data from the entire respiratory cycle through deformable registration. In addition, we use the transformation maps to generate a 4D PET with statistics comparable to the single RS image. **Method and Materials:** A single FOV of a pancreatic cancer patient was acquired via the gated PET mode on a GE Discovery ST PET-CT scanner. These gated images were registered using a mutual information / B-splines registration algorithm, and superimposed. A 4D PET series spanning the full respiratory cycle was generated, and fused onto a 4D CT. **Results:** The SNR of the RS image showed an increase of 15% over a single gated reconstruction. Activity-volume histograms of radiotracer activity surrounding the pancreatic lesion revealed that the ungated PET showed 33% greater tumor volume (using a 40%-of-maximum threshold) than the RS image. The reconstructed 4D PET fused well with the 4D CT, providing a clearer view of radiotracer distribution over the respiratory cycle than was possible using gated reconstructions. **Conclusion:** Retrospective stacking enabled better integration of temporally varying PET and CT series by reducing radiotracer smearing due to respiratory motion, while at the same time increasing the SNR beyond the poorer statistics inherent in gated PET acquisition. Noise-reduced 4D PET images could also be generated for fusion with 4D CT.

Joint Imaging/Therapy Symposium Room 6B

Technologies for In-Vivo Small Animal Imaging

TU-D-J-6B-01

Small Animal PET and SPECT: Instrumentation, Performance, and Applications

CS Levin*, Stanford University School of Medicine, Stanford, CA

In recent years both industrial and academic institutions have been intrigued with the possibility of using *in vivo* imaging assays in small animal models to study cellular and molecular processes associated with diseases such as cancer, heart disease, and neurological disorders. The ultimate goals of these *in vivo* imaging efforts are to facilitate the discovery of new drugs and treatments for disease and accelerate their translation into the clinic. Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) are highly sensitive *in vivo* imaging modalities that can detect extremely low concentrations of radionuclide-labeled probes that target the disease process of interest at the molecular level. This presentation will review PET and SPECT small animal imaging instrumentation requirements, challenges, performance characteristics, and applications in imaging subtle molecular signals associated with disease.

TU-D-J-6B-02

Optical Tomographic Imaging of Small Animals

A Hielscher*, Columbia University, New York, NY

Diffuse optical tomography (DOT) is emerging as a viable new biomedical imaging modality. Using visible and near-infrared light, in the range of 500 to 900 nm, this technique can probe absorption as well as scattering properties of biological tissues. The main applications are currently in brain, breast, limb, and join imaging; however, the area of optical tomographic imaging of small animals is attracting increasing attention. This interest is mainly fueled by recent advances in transgenic manipulation of small animals that has led to many models of human diseases. Using these models it is possible to link specific genes, proteins, and enzymes to molecular, and cellular processes that underlie various disorders. In addition, the advent of novel biochemical markers that are sensitive to molecular processes, defect genes, and cell receptors, makes it for the first time possible to detect diseases on a molecular level long before actual phenotypical symptoms appear.

Small animal optical tomography has several advantages over other, more traditional, imaging modalities. For example, optical markers emit low-energy near-infrared photons that are less harmful than more energetic gamma rays emitted from radioactive markers (used in SPECT and PET, for instance). This simplifies synthesis procedures and experimental designs and will be of particular importance for future applications in humans. Furthermore, optical methods typically offer higher sensitivity (as compared to MRI and SPECT) and are relatively inexpensive (as compared to PET, SPECT, and MRI).

In this paper we will review underlying principles in optical tomographic imaging as they apply to studies involving small animals. We will describe the basic contrast mechanism involved in imaging of endogenous as well exogenous contrast agents. In addition we will discuss specific features and advantages of different types of optical instrumentation currently available, such as steady-state, frequency-domain, and time-resolved imaging systems. Furthermore we will describe in detail the structure of commonly used image reconstruction schemes and algorithms and point to still existing challenges. Finally, we will provide an overview of the most recent literature in optical small animal imaging, specifically in the areas of blood oximetry, fluorescence and bioluminescence imaging.

Educational Objectives:

1. To understand significance, potential, and limits of optical tomographic small animal imaging.
2. To understand the contrast mechanisms that underlie optical tomographic imaging.
3. To understand the basic measurement instrumentation used in optical tomographic imaging.
4. To understand the fundamental concepts and problems involving optical tomographic image reconstruction algorithms.
5. To learn about the major applications of this novel technology.

TU-D-J-6B-03

Physics and Applications of Preclinical Micro-Ultrasound Imaging
S Foster*, University of Toronto, Toronto, Ontario, CA

Bioresearch in functional genomics is poised to make major contributions to our understanding of normal development and human disease. This promise will, in part, rely on the development of new micro-imaging technologies to provide quantitative longitudinal assessment of morphological and functional development of normal and abnormal tissues. In addition, imaging tools will need to be further refined to enable high throughput phenotypic assessment of the rapidly escalating numbers of targeted and random mouse mutations. This presentation will focus on the development of high frequency (20 to 70 MHz) ultrasound biomicroscopy (UBM) for mouse imaging. While UBM does not provide molecular specificity, it has the advantage of low cost, rapid imaging speed, portability and high resolution (30-100 microns). The physics of high frequency ultrasound will be reviewed and the latest developments in instrumentation will be presented. Applications of 2 and 3D imaging to mouse cardiovascular assessment, cancer and ocular diseases will be described. Recent advances in 3D UBM imaging now permit the volumes of growing experimental tumors to be assessed with relative ease. Examples of tumor growth studies will be presented. In particular, a human melanoma (MeWo) and a model of retinoblastoma will be examined. Further analysis of Doppler and other flow related data offers insight to microvascular development and its alteration during treatment. This is particularly relevant to angiogenesis and antiangiogenic treatments. As an example of antiangiogenic therapy, a study of DC101 (ImClone Systems), a monoclonal anti-VEGFR2 antibody will be presented.

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TU-D-J-6B-04

Technology for Small Animal X-Ray and CT Imaging
JM Boone*, UC Davis Medical Center, Sacramento, CA

The laboratory mouse and other small rodents have become a principal tool of biomedical researchers. The ability to manipulate the genetic component of the mouse by adding or deleting specific genes has proved quite valuable in virtually all areas of medical research, from neurodegenerative diseases to cancer. In many applications of mouse research, a better understanding of the phenotype of a specific mouse model is important. X-ray imaging including computed tomography (CT) of the mouse therefore is an important aspect of genetic research. In this presentation, novel high resolution technologies for x-ray imaging of the mouse will be discussed. Applications of new classes of contrast agents designed for animal use in concert with x-ray and CT imaging will also be presented. Radiation dosimetry methods pertinent to small animal imaging with x-rays will be described in detail. The role that x-ray and CT images have in conjunction with physiological imaging techniques (nuclear and PET imaging) will also be described.

Professional Symposium Room 618

Medical Errors and Medical Physics

TU-D-P-618-01

Medical Errors and Medical Physics
M Herman*[1], B Thomadsen*[2], P Dunscombe*[3], (1)Mayo Clinic, Rochester, MN, (2)University of Wisconsin, Madison, WI, (3)Tom Baker Cancer Centre, Calgary, AB, CA

This session will be devoted to the occurrence of medical errors, approaches to error reduction and implications for the practice of medical physics. A background on errors in medicine through the Institute of Medicine reports and some more specific examples in medical physics will overview the critical nature of our responsibility to quality patient care. Medical errors occur for many reasons and as clinical medical physicists, we are responsible for discharging duties in imaging and therapeutic procedures that directly impact the quality of patient care. We have fiduciary responsibility to be properly trained and prepared to carry out these critical tasks.

Even under the best circumstances, errors occur. The three speakers will review errors in radiotherapy in detail, discuss approaches to patient safety and error reduction, including government and regulatory oversight, and applications and implications for medical physics training and practice, again with specific examples to highlight importance.

Errors in medical settings crashed into the forefront with the release in 1999 of the Institute of Medicine's report, 'To Error is Human' in which they give the estimate that up to 98,000 patients a year die because of errors in their healthcare delivery. After a slow start, healthcare providers are making great progress in improving the situation. Much of improvement follows application of techniques in error reduction that have proven effective in industries that require high reliability, such as aviation. Even so, differences in the nature of the work necessitate adaptation of the techniques to the clinical setting. The following observations follow from studies of errors that have occurred in radiotherapy: 1. While particular failures in medicine differ, the nature of the error parallel those in industry; 2. Errors don't happen from a single cause, but are surrounded by complicating situations and enabling factors; 3. Errors are often surrounded by indicators of things going wrong that are ignored; 4. Errors often follow violations in protocols; 5. Errors often occur with new procedures, variations on common procedures, or following hand-offs; 6. Equipment design often creates situations likely to lead to failures; 7. Lack of information, either from lack of training or information not being passed, plays a significant role in most events; 8. Persons involved often react to what they expect to be happening rather than what is actually happening; 9. Distraction and rushing due to pressure and other assignments often plays a critical role; and 10. Communication between parties often leads to erroneous actions. Most of these are not startling, but solutions that seem obvious often fail to correct underlying situations. The Joint Commission has made many error-reduction methods requirements for accreditation of healthcare providers. Applications of error prevention techniques will be discussed.

Quantitative risk analysis in radiation therapy can be performed and subsequently integrated into clinical operations. Many reports in the medical and popular press over the last several years have heightened the public's awareness of the risks they are exposed to when interacting with a health care system. In the radiation therapy community, we have learned of many major incidents involving multiple patients, occurring across the world. While quality assurance and quality control are reasonably well developed in radiation therapy, these and other operational issues are generally not firmly anchored to a risk analysis and management framework. Risk can be defined as some combination of the probability and consequence of an undesired outcome. To gain further insight into the probability component, we have concentrated on the development of a fault tree, similar to that previously applied to brachytherapy, and have shown that it is able to accommodate the external beam radiation therapy errors reported to date. The fault tree is based on a system map for radiation therapy but its major branches are applicable to other areas of medicine. It is apparent from our fault tree based analysis that the various error reports and databases available do not paint a consistent picture of the origins of serious misadministrations in radiation therapy. The Equivalent Uniform Dose is proposed as a suitable consequence metric, capturing, as it does, both dose and volume elements of a correct or incorrect treatment. The fault tree and consequence framework developed can be linked to operational and resource allocation decisions. These include such items as specific identification of responsibilities within a radiation treatment program, quality assurance measures and incident reporting. As risk management and quality management are different facets of the same issues, efforts to reduce risks to patients will lead to improved quality in routine radiation therapy activities. Following a review of common approaches to error analysis in medicine, a fault tree and consequence metric for use in radiation therapy are proposed. The value of this type of risk analysis approach to operational risk management activities is explored in detail. With a generic and structured approach to the quantification of errors in radiation therapy, it is possible to configure operational components of a clinical program so that risks to the patient and delivery organization are managed.

The session will end with a discussion of these critical issues with the audience.
Educational Objectives:
1. To understand the nature of errors that have occurred in radiotherapy;

2. To understand how knowing the nature of errors can lead to remedial actions; and
3. To learn what the Joint commission on Accreditation of Healthcare Organizations has been doing to improve patient safety.
4. To understand the direct implications on the training and practice of medical physicists
5. To understand the application of quantitative risk analysis of medical errors.

Therapy Scientific Session Room 617
New Radiopharmaceuticals and Emerging Applications

TU-D-T-617-01

Comparison of LDR to PDR Dose Distributions: A Monte Carlo Study

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Purpose: 1) To validate a Monte Carlo (MC) model of the Ir-192 pulsed-dose rate (PDR) source inside the Fletcher-Williamson (FW) ovoid using radiochromic film measurements. 2) To compare the FW dose distributions in water to those of Cs-137 low-dose rate (LDR) pellet inside the Selectron Fletcher-Suit-Delclos (FSD) ovoid*. **Method and Materials:** Detailed mechanical drawings of the FW colpostat were obtained from the vendor. MCNPX 2.5e MC code was used to model the small right FW ovoid and an Ir-192 source (mHDR v2) centered within the ovoid. MC models of actual and virtual Ir-192 source in air were also run to derive the conversion from contained to apparent activity. MD-55 radiochromic film was placed in a polystyrene phantom at a plane parallel to and displaced medially 2.0 cm from the long axis of the colpostat. To compare with the FSD ovoid, MC runs in a 30 cm water sphere were run for common ovoid loadings of 5, 10, 15, and 20 mgRaeq. **Results:** MCNPX calculated dose relative to film measurements is within ±2% or 2mm distance-to-agreement for 92% of the dose grid. For the FW simulations in water, the overall shapes were found to be similar in regions away from the shields to those obtained for the FSD ovoid; however, large but localized deviations were found in high dose-gradient regions close to the rectal and bladder shields, mainly due to differences in source and shields geometry. **Conclusion:** The dose distributions predicted by MCNPX are in good agreement with the film results. Dose-rate atlases calculated in clinically-relevant 2D planes around the FW and FSD ovoids provide information to aid in the transfer of current LDR intracavitary brachytherapy practice to that using PDR for treatment of gynecological cancers. **Conflict of Interest:** Partial support by Nucletron Corporation.

* Gifford, Med. Phys. 31, 1808, (2004)

TU-D-T-617-02

Dose Conformity Improvement Using Lead-Shielded Intracavitary Mould Applicator for Patients with Rectal Carcinoma

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Purpose: We present dose distribution results of Monte Carlo (MC) based treatment planning, employing Intracavitary Mould Applicator, used in pre-operative high dose rate brachytherapy treatment of patients with rectal carcinoma, with the central lumen filled with lead as a shielding material. To justify the application of this shielding technique, the MC dose kernel calculations have been compared with experimental measurements. **Method and Materials:** Eight catheter channels are equally distributed over the circumference of the applicator with a central lumen intended to be used for insertion of an additional extending central catheter. Two dose kernels have been calculated for 192Ir source using the DOSXYZnrc Monte Carlo code: one for water phantom that includes air in the central lumen and another one for water phantom that includes lead shielding in the central portion of the applicator. For the dose measurements, we have used an Exradin planar ionization chamber (Model A14P). For the sake of MC dose kernel experimental verification, we have simulated the experimental phantom with scoring regions corresponding to the measurement points to increase the number of simulated photons and decrease the resulting uncertainty of the scored dose. For the clinical result presented in this paper, we have calculated two dose distributions: one with the air-kernel, and another one with the lead-kernel. Both distributions have been optimized in such a way to cover the target volume with the 100 % isodose surface. **Results:** Experimental dose ratios for particular points with and without lead shielding in the central position of the applicator differ from MC calculated ratios by 1 % for points in close proximity and up to 10 % for distal points. **Conclusions:** In this work, we demonstrated the increase in dose conformity using lead-shielded Intracavitary Rectal Mould Applicator for patients with locally advanced rectal carcinoma.

TU-D-T-617-03

Assessment of a Prostate Treatment Plan Using Directional Brachytherapy Sources

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Purpose: To evaluate the effect of using newly developed directional sources in a prostate brachytherapy treatment plan. **Method and Materials:** Directional sources contain a radiation shield in part of its interior that reduces significantly the intensity of radiation emitted in the shielded direction. They have a similar dose distribution as non-directional sources on the unshielded side. We use an adjoint region of interest based optimization system to generate a plan for 0.546 U non-directional ^{125}I sources to deliver a prescribed dose (D_p) of 145 Gy to the prostate and then manually replace some sources with the same strength of directional sources. The orientation and position of the directional sources have been selected to maximize V100 (percent of prostate receiving 145 Gy and higher), minimize R90Gy (percent of rectum receiving 90 Gy and higher) and minimize V125 and eliminate V150 for the central prostate regions including urethra (percent of volume receiving 125% of D_p (181 Gy) and 150% of D_p (217 Gy), respectively). **Results:** V100 of the prostate target region increases from 97.5% to 98.9%, the central prostate region including urethra, receives the full uniform prescribed dose, V125 drops from 61.7% to 49.2% and the V150 of 2.24% is eliminated. There is a large reduction in R90 Gy from 53.7% to 20.6% for the anterior retal wall, which significantly reduces the probability of rectal morbidity. All treatment plan indicators are improved with use of directional sources. **Conclusion:** Directional sources can allow the conflicting goals of increasing prostate target V100, decreasing R90Gy, decreasing V125 and eliminating V150 of the central prostate regions including urethra to be independently optimized, yielding a better treatment to the prostate with less rectal and urethral morbidity.

TU-D-T-617-04

Dose Rate Constant of the Cesium-131 (model CS-1) Interstitial Brachytherapy Seeds Measured by Thermal-Luminescent Dosimeter (TLD) and by Gamma-Ray Spectroscopy

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Purpose: To measure the dose rate constant of the model CS-1 low-energy interstitial brachytherapy seeds containing ^{131}Cs. **Method and Materials:** Eight ^{131}Cs seeds were obtained from the seed manufacture (IsoRay). The air-kerma strength of each seed was measured by the manufacture whose dosimeter calibration is traceable to the air-kerma strength standard established for the ^{131}Cs seeds at NIST (1σ uncertainty < 1%). The dose rate constant of each seed was measured by two independent methods: One based on the actual photon energy spectrum emitted by the seed using gamma-ray spectroscopy and the other based on the dose-rate measured by thermal-luminescent dosimeter (TLD) in solid-water phantoms. **Results:** The dose rate constant in water determined by the gamma-ray spectroscopy technique and by TLD dosimetry are 1.066± 0.049 $Gyh^{-1}U^{-1}$ and 1.069 ± 0.096 $cGyh^{-1}U^{-1}$, respectively, showing excellent agreement with each other. These values, however, are approximately 15% higher than a previously reported value of 0.915 $cGyh^{-1}U^{-1}$ (*Med. Phys.* **31**, 1529-1538, 2004). Since the average photon energy emitted by ^{131}Cs is on the order of that emitted by ^{125}I, the previously reported value could only be possible if the ^{131}Cs seeds had generated a significant amount of lower energy fluorescent x-rays. Fluorescent x-rays at 16.6 and 18.7 keV originating from Niobium in the seed construction were indeed measured in the energy spectra but their yields were not sufficient to lower the dose rate constant to 0.915 $cGyh^{-1}U^{-1}$. **Conclusion:** The dose rate constant of the model CS-1 ^{131}Cs seeds was carefully determined using two independent methods. A

large discrepancy (> 15%) was observed against a previously reported value. Additional determination of the dose rate constant may be needed to establish an AAPM recommended census value.

TU-D-T-617-05

TG-43U1 Based Dosimetric Characterization of Model 67-6520 Cs-137 Brachytherapy Source

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Purpose: Dosimetric characteristics of a newly designed Cs-137 source (Model 67-6520) by Isotope Product Laboratories were determined using experimental and theoretical methods. These determinations were performed using TG-43U1 for distances larger than the active length of the source and along-away matrix for shorter distances. **Method and Materials:** Radial dose function, dose rate constant, 2D and 1D anisotropy function of the new Cs-137 source were determined following updated AAPM Task Group 43 (TG-43U1) recommendations. The experimental setup used for the determination of these parameters consisted of 1.0 x 1.0 x 1.0 mm^3 and 3.2 x 3.2 x 0.89 mm^3 TLD-100 LiF thermoluminescent dosimeters in Solid Water™ Phantom Material (40 x 40 x 20 cm^3). TLD's were read using a Harshaw model 3500 TLD reader. The experimental results were compared to theoretical data using Monte Carlo simulations in liquid and Solid Water™.
A Monte Carlo N-particle Transport Code (MCNP4C2) was used to calculate the dose rate distribution in Solid Water™ and liquid water. This code is capable of accounting for photoelectric, coherent, Compton and pair production interaction processes. The photon interaction cross section file used in this study was DLC-200 library distributed by the Radiation Shielding Information Computing Center (RSICC). In this study, up to $20x10^6$ photons were used for each simulation. Calculations were set up in the same design format as the TLD experiments. **Results:** The calculated dose rate constant in liquid water and Solid Water™ were found to be 0.961 $cGyh^{-1}U^{-1}$ and 0.962 $cGyh^{-1}U^{-1}$, respectively. In addition, there was good agreement between the measured and calculated dose rate constant, radial dose function and the anisotropy function in Solid Water™. **Conclusion:** The dosimetric characteristics of the IPL 67-6520 Cs-137 source were determined using the TG-43U1 recommendation. The characteristics of the new Cs-137 source are comparable to the other commercially available sources.

TU-D-T-617-06

The Optimization of Dose Delivery for Intraoperative High-Dose-Rate Radiation Therapy Using Curved HAM Applicators

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Purpose: To quantify the effect of the curvature of flexible applicators on the dose distribution in high-dose-rate intraoperative radiation therapy (HDR-IORT). **Method and Materials:** Treatment planning was performed with flat Harrison-Anderson-Mick applicators using ^{192}Ir as the radioactive source, and dwell times were optimized using dose-point optimization techniques. These optimized dwell times were then used for the curved applicators, and the dose distributions that would actually be delivered to patients were determined. Shallow, moderate, and steep curvatures were considered. The discrepancies in dose distribution resulting from the applicator's curvature were quantified, and the regions receiving significant underdoses or overdoses were identified. **Results:** The dose directly below the central catheter was strongly dependent on the curvature of the applicator. Steep parabolic curves caused underdoses as large as 19% at the prescribed depth of 1 cm normal to the convex side of the applicator surface. The rate of dose reduction with increasing distance from the applicator surface was also greatly affected by applicator curvature. The local dose distribution was not greatly affected by the number of catheters. On the concave side of the applicator, curvature pushed the isodose curves from the applicator surface, causing overdosing. Data from these experiments could be used to create a simple library of treatment plans for curved geometries to complement existing libraries for flat applicators. **Conclusion:** The curvature of the applicator profoundly affects dosimetry and can be exploited to optimize coverage of the target during HDR-IORT procedures. To ensure accurate dose delivery, these dose perturbations must be accounted for in the planning process. We recommend maintaining a dosimetry atlas of various applicator sizes and curvatures in addition to one for flat applicators.

TU-D-T-617-07

Treatment Plan Validation of the Xoft AXXENT™ X-Ray Source

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Purpose: Accuracy of delivered dose compared to BrachyVision™ generated treatment plans was tested using both a calibrated miniature air ionization chamber to measure dose at the prescription point, and radiochromic film to map isodose contour lines. Quantitative and qualitative comparisons of the total dose and contour shapes were made. **Method and Materials:** Xoft applicator balloons were held in a water phantom with a Solid Water™ fixture. A PTW model 34013 ionization chamber connected to a PTW UniDos electrometer, and read into a computer, were used to measure the dose at the prescription point. Films were held in the fixture in the plane of the source, offset by 5 mm. The Xoft Axxent controller performed sample treatments including stepping of the source for four combinations of balloon size and operating voltage. Film samples were digitized and converted to dose values through a specially developed calibration curve. Comparison of isodose contours with the film-measured dose was accomplished with specially written image analysis algorithms, which compared the measured values with predicted along the isodose contours. **Results:** Dosimeter based dose measurements agreed with prescription to within 11% worst case, with an RMS error of 8%. Film analyses quantified deviation from isodose contours as a function of polar angle, with relative RMS deviations well under 10%. However limitations in the accuracy of film calibration limited absolute accuracy to just over 20%, with systematic behavior attributable to limitations of the fitting function. **Conclusion:** Validation of treatment plans were performed using direct dosimetry and film based measurements. Novel image analysis tools were developed to allow numerical evaluation of film dose to isodose contours. **Conflict of Interest:** Research was supported by Xoft, Inc.

Therapy Symposium Room 6E

Why, What, and How Much QA is Necessary for IMRT?

TU-D-T-6E-01

Why, What, and How Much QA Is Necessary for IMRT?

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Intensity –modulated radiation therapy (IMRT) represents one of the most significant technical innovations of the modern day radiation therapy. Unlike conventional three-dimensional conformal radiation therapy (3DCRT), both the treatment planning and delivery of IMRT are more complex and less intuitive to the users. Thus, IMRT requires much more diligence in understanding the whole planning and delivery process, associated quality assurance procedures, QA frequencies, and QA tolerance limits with action levels over and beyond what is currently understood for 3DCRT. The complexity of IMRT technology has vastly outgrown our current task group checklist system. It will now require the implementation of new and innovative paradigms of science and engineering of quality management. It is just not possible to develop a single checklist for comprehensive IMRT QA.
This panel will describe the objective technical details of what **should** be done for IMRT QA. It will address **why** we do **what** we do and **how** we could do a better job of allocating our limited resources. The presenters will expound on the influence that the specific wording and interpretation of current procedural terminology (CPT) codes has on IMRT QA and how it may change in the future.

TU-D-T-6E-02

Panel Discussion - Why, What, and How Much QA Is Necessary for IMRT?
Panelists: P Xia*[1], G Ezzell*[2], M Sharpe*[3], (1) UC San Francisco, San Francisco, CA, (2) Mayo Clinic Scottsdale, Scottsdale, AZ, (3) Princess Margaret Hospital, Toronto, ON, CA

Workshop Room 608
DOT HazMat Workshop

TU-D-W-608-01
Department of Transportation Hazmat Employee Training for Shippers of Radioactive Materials
R Parker*, Baton Rouge, LA

Medical Physicists are frequently involved in shipping radioactive materials or supervising those who do. Current U.S. Department of Transportation Hazardous Material Regulations, 49 CFR Parts 171 - 185, require hazmat employees to have documented training specified in 49 CFR 171 Subpart H. A hazmat employee is defined as an individual who: (1) loads, unloads or handles hazardous material; (2) manufactures, tests, reconditions, repairs, modifies, marks or otherwise represents containers, drums or packagings as qualified for use in the transportation of hazardous materials; (3) prepares hazardous materials for transportation; (4) is responsible for safety of transporting hazardous materials; or (5) operates a vehicle used to transport hazardous materials. Recurrent training is required at least once every three years. (The IATA two year training interval is not applicable and is generally misunderstood.) FAA has escalated inspection and enforcement and facilities who ship radiopharmaceuticals to other laboratories, return radiopharmaceuticals or radioactive sources to suppliers or otherwise ship radioactive materials have been cited for failure to provide and documents this training.

The course will cover typical shipments by air and highway which are encountered in a medical institution. Items such as fissile materials, highway route controlled quantities, rail shipments, vessel shipments and such will be omitted, although specific questions may be addressed. A major objective of the course is to provide the process of shipping radioactive material in a sequential and logical fashion. Radioactive material shipments of excepted packages and Type A packages will be emphasized. The new exempt material activity concentrations and exempt consignment activity limits will be presented, as well as the new international proper shipping names and UN numbers which become mandatory on October 1, 2004.

The program is designed to meet the DOT training requirements, but it is the hazmat employer's responsibility to ensure that each hazmat employee is properly trained. It is the hazmat employer's responsibility to determine the degree to which this course meets the employer's requirements, including contents of the course and the examination. Participants will gain sufficient knowledge to prepare training programs for others in their institutions. Handouts will summarize the course. A feature handout is a composite table which provides A_1, A_2, RQ, Exempt Concentration, and Exempt Consignment values in a single table in both Becquerel and Curie units. The examination at the conclusion will be self graded in the course and retained by the participant to form part of his training documentation. Certification of course attendance will be through the AAPM CEU documentation system.

Imaging Scientific Session Room 611
Imaging Dosimetry and Quality Control

TU-E-I-611-01
Comparison of Radiation Dose Using Full Field Digital and Conventional Screen-Film Mammography in a Screening Clinic
E Gingold*, Thomas Jefferson University, Philadelphia, PA

Purpose: To evaluate radiation doses delivered by an amorphous selenium based full-field digital mammography (FFDM) system, and to determine if the expected reduction in average glandular dose (AGD) resulting from the increased efficiency of the digital detector is realized in clinical practice. A secondary purpose was to determine clinical exposure parameters for digital mammography that maintain a level of image noise consistent with screen/film mammography. **Method and Materials:** Phantom material that approximates breast tissue (50% adipose, 50% glandular) was used for direct comparison of dose between the two clinical mammography units, one digital and one conventional. The mammographic view, compressed breast thickness, kilovoltage, milliampere-second product, and K-edge filter were recorded for images of randomly-selected patients examined on each machine. Entrance skin exposure was calculated from measurements, and AGD was estimated using normalized exposure-to-dose conversion factors that assume 50% adipose and 50% glandular breast composition. A two-tailed student t-test was used to compare the patient doses. **Results:** No difference was observed in the mean AGD delivered by the two mammography units over a wide range of compressed breast thicknesses and compositions. For compressed breast thickness above 7 cm, the dose was significantly lower for the FFDM unit ($P<0.05$) due to the use of higher kilovoltage and rhodium filtration, and correspondingly lower values of mAs. **Conclusion:** The exposure parameter selection algorithm employed by the FFDM unit does not reduce dose compared with a conventional mammography unit for a wide range of breast thicknesses. Users wishing to reduce AGD should consider using manual techniques, and developing technique charts to achieve the desired compromise between dose and image quality. The algorithm used by the conventional mammography unit to automatically select kVp resulted in extended exposure times and unnecessarily high values of mAs and AGD because of its relatively low upper bound on kVp.

TU-E-I-611-02
The Dosimetric Effect of Unrealistic Arm Structure of Stylized Human Model
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Purpose: To investigate the dosimetric effect of unrealistic arms in stylized human models on organ doses for external irradiation geometry by comparing organ doses of ICRP74 to those from four realistic tomographic models for gamma radiation in lateral geometry. **Method and Materials:** By comparing the transversal images of the representative stylized model, MIRD (Medical Internal Radiation Dose) phantom to those of VHP (Visible Human Project) human, it was obviously manifested that arms of the MIRD phantom are unrealistically included in trunk region. Dose conversion coefficients of ICRP 74 were adopted as representative dosimetric data based on stylized models. Photon dose conversion coefficients of four organs (lungs, stomach, esophagus, and liver) which seemed to be sensitively affected by arms in lateral geometries were compared with those from four realistic tomographic human models: KTMAN-1, KTMAN-2, VIP-man, and Zubal phantom. All models have arms except for KTMAN-1 of which arms were upward stretched when scanned. Organ doses for lateral geometries were computed by MCNPX2.4 using KTMAN-1, KTMAN-2 and Zubal phantom, and those of VIP-man were obtained from published article. KTMAN-1 and KTMAN-2 are Korean tomographic models under preparation for publication. **Results:** Absorbed dose conversion coefficients of four organs from ICRP 74 were higher up to 88% (esophagus) than tomographic models. The overestimation was caused by less shielding offered by arms-included torso in stylized models than arms-attached torso in tomographic models. Organ doses of armless KTMAN-1 were higher than those of other tomographic models, and less than those from ICRP 74 as expected. **Conclusion:** The unrealistic arms in stylized models cause overestimation of some major organ doses for external photon beams in lateral geometry up to 88% depending on individuals. One should keep in mind the overestimation when using stylized models for dose evaluation of medical staffs.

TU-E-I-611-03
The UF Series of Tomographic Anatomic Models of Pediatric Patients
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Purpose: To develop a series of detailed tomographic computational models of pediatric patients for the use in patient dose evaluation under various diagnostic and therapeutic procedures. **Method and Materials:** IDL-based image manipulation tools were utilized to develop five

tomographic head and torso models of different pediatric patients (9-month male, 4-year female, 8-year female, 11-year male, and 14-year male) from CT image data of live patients. The models were created from fused images taken from head and CAP CT exams of the same individuals (9-month and 4-year models) or two different individuals of the same sex with close age (8-year, 11-year, and 14-year models) since continuous images from head to CAP were not available. During the process, the image resolutions and slice positions were adjusted based upon their anatomy and engineered into single head-torso image sets. Lungs, bones, and adipose tissues were automatically segmented by using window leveling of original CT numbers. The remainders were either semi-automatically or manually segmented with the aids of both anatomical knowledge and available image processing techniques. Skin layers were created by adding voxels along the contour of the bodies. **Results:** Total of five high-resolution pediatric tomographic model series were developed. More than 60 regions of interest were identified for each model to be used for the organ absorbed dose calculation and consequent effective dose assessment. Organ masses are compared to the age-interpolated values of ICRP 89 reference data. **Conclusion:** This work provides the medical physics community with tomographic computational models, which are readily adaptable to general Monte Carlo codes to evaluate radiation risks of pediatric patients under various radiation procedures.

TU-E-I-611-04

Bone Marrow and Bone Endosteum Dosimetry Methods Comparison for External Photons

C Lee*, C Lee, W Bolch, Univ Florida, Gainesville, FL

Purpose: To compare and verify different bone endosteum and bone marrow photon dosimetry methods through the use of a high-resolution micro CT-based radiation transport model. **Method and Materials:** Two different Monte Carlo dosimetry algorithms for bone endosteum and bone marrow were compared to a high-resolution microCT image-based radiation transport model developed in our laboratory. Bone marrow dosimetry methods are (1) the dose response function method by Eckerman (DRF), and (2) the mass energy absorption coefficient ratio method (MEAC). Bone endosteum dosimetry methods include (1) DRF method and (2) homogeneous bone dose approximation (HGB). Each method was compared to results obtained from the microCT-based paired-image radiation transport (PIRT) model. Two ex-vivo bone samples of a 66-year male (lumbar vertebrae and cranium) were chosen for the comparison because of their distinctively different microstructures. Simple mono-energetic parallel photon beams were simulated from 0.01 to 4.0 MeV. **Results:** For the bone marrow dose, the DRF method shows good agreement with PIRT result in the lumbar vertebra, but showed over estimates of bone marrow dose in the cranium, while the MEAC method shows good agreement with PIRT in both bone sites. For the bone endosteum dose, the DRF method shows closer results to the PIRT model at lower energies, but shows significant over- estimates of endosteum dose in higher photon energies. This can be explained by the fact the Eckerman model assumes that secondary electrons are followed through an infinite expanse of trabecular spongiosa, with no loss of energy to the bone cortex at high energy. **Conclusion**: For the bone marrow dose assessment, the MEAC method seems to be the best choice among the methods considered, while for the bone endosteum dose, the HGB method shows better agreement with PIRT than is seen with the DRF method, especially at higher photon energies.

TU-E-I-611-05

Point-To-Organ Dose Scaling Factors for Use in Pediatric Radiology

R Staton, A Jones*, W Bolch, D Hintenlang, University of Florida, Gainesville, FL

Purpose: The purpose of this study was to develop a comprehensive set of point-to-organ dose scaling factors (SF_{POD}) for pediatric radiology. **Method and Materials:** A physical tomographic newborn phantom was used in conjunction with an identical computational model to develop SF_{POD}. SF_{POD} were developed using Monte Carlo simulations of various radiographic and CT exams of a pediatric patient. Doses calculated included both organ doses and point doses, which were calculated at the same places at which doses were measured using MOSFET dosimeters in the physical phantom. Bone marrow dose was calculated using fluence-to-dose conversion coefficients. The resultant SF_{POD} values can then be used to calculate organ doses in the physical phantom from point dose measurements. The SF_{POD} were calculated at several energies and an average was used to generate general SF_{POD}. **Results:** Individual SF_{POD} ranged from 0.82 to 1.08. Also, the SF_{POD} for the sigmoid colon/rectum was 1.71. This was due to improvements or updates to the computational phantom that occur on a regular basis as more sophisticated tools become available. Therefore, SF_{POD} are useful not only for organ dose calculation in the physical phantom, but can also be used to incorporate improvements to the computational phantom into the physical phantom when physical alteration is impossible. **Conclusion:** This work demonstrates the benefits of having both physical and computational phantoms created from the same data set. A physical phantom alone is of limited use due to errors associated with only measuring point doses in organs. A 20% uncertainty in dose for an exam may seem trivial, but consider a pediatric patient subjected to 10 exams during childhood. The same 20% uncertainty propagated over 10 exams takes on new meaning. Also, it has been demonstrated that improvements to the computational phantom can be transferred to the physical phantom by using associated SF_{POD}.

TU-E-I-611-06

A Novel Shielding System That May Eliminate the Need for Lead Apparel During Fluoroscopic Procedures

V McCormick*, J Goldstein, W O"Neill, M Pica, William Beaumont Hospital, Royal Oak, MI

Purpose: To demonstrate the effectiveness of a novel shielding system that completely shields the operator and attending staff during fluoroscopic procedures. **Materials and Methods**: The enclosure system, developed by ECLS, Inc., is composed of lead glass, leaded drapes and a steel frame. Most of the patient's body and the x-ray unit are on one side of the enclosure. The leaded glass and leaded drapes contain 1 mm and 0.5 mm lead equivalency, respectively.

All exposure measurements were taken with a Radcal 9010 survey instrument with a 60cc ion chamber. The scatter phantom was composed of 7 inches of Acrylic and 3 mm Aluminum. Measurements were taken at various positions in the room during boosted fluoroscopy.

Measurements were also taken within a lead apron, with 0.5 mm lead equivalency, at 2 ft from phantom with no interposed shielding. **Results**: The maximum exposure rate was measured at the operator position and was 1.9 mR/h, 2.5 ft from the phantom. A corresponding measurement on the phantom side of the shield was 824 mR/h. The maximum exposure rate seen within the lead apron was 13.7 mR/h. The shielding system performed better than the 0.5 mm lead equivalency lead aprons. A staff member standing at the operator's position for all 211 hours of fluoro time last year in that lab would have receive 401 mrem, well below 10% of the legal limit of 5000 mrem whole body allowed for occupational exposure. **Conclusion**: This shielding system provided protection superior to that of a standard lead apron. It is hoped that the use of this shielding system may eliminate the need for lead apparel during fluoroscopic procedures. **Conflicts of Interest**: This research is partially funded by ECLS, Inc.

TU-E-I-611-07

Characterization of Two Optically Stimulated Luminescence (OSL) Dosimeter Systems for Monitoring Entrance Skin Dose During Interventional Procedures

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Purpose: There is a great concern of patient skin injury and a demand for an effective technique for direct measurement of patient dose in real-time. We have characterized two dosimeter systems for possible future development of a clinically feasible dosimetry system. Success of this investigation may lead to significant reduction of patient radiation dose and skin injury. **Method and Materials:** High-sensitivity, fiber-optic dosimetry systems based on OSL from Al_2O_3: C and KBr:Eu single crystals (detectors) were developed at Oklahoma State University. The physical characteristics of the detector systems were investigated using clinical fluoroscopic machines. The detector's dependence on x-ray energy, exposure rate, and the angle of x-ray incidence were evaluated. The data from the dosimetry systems are normalized to ion chamber readings under the same conditions. The detectors were attached to an anthropomorphic chest phantom for physicians to evaluate the visibility of the detectors in

the fluoroscopic image. A mathematical model was developed to simulate data sampling of the KBr:Eu system when used with pulsed fluoroscopic equipment. **Results:** Both types of detectors were nearly invisible under various kVp conditions for typical fluoroscopic procedures. Across the energy range of 60 to 120 kVp, energy dependence was less than 23% for Al_2O_3:C system and less than 8% for the KBr:Eu system. Dose rate dependence was less than 2.1% for the KBr:Eu system, but the Al_2O_3:C system responded too slowly. Angular dependence was less than 6% for the Al_2O_3:C system and 3.5% for the KBr:Eu system. The mathematical model shows that the KBr:Eu system should function consistently under various pulsed fluoroscopic operations. **Conclusion:** The OSL detectors are of small size, yet sensitive to low exposure, and exhibit practically invisible in fluoroscopic images. Response to variation of fluoroscopic x-ray parameters is acceptable. Both systems show promise for a clinically feasible skin dose dosimetry system.

Workshop Room 608
DOT HazMat Workshop

TU-E-W-608-01
Department of Transportation Hazmat Employee Training for Shippers of Radioactive Materials
R Parker*, Baton Rouge, LA

(see abstract: TU-D-W-608-01)

Professional Symposium Room 618
Maintenance of Certification Update/ Educational Opportunities and CARE

TU-E-P-618-01
Maintenance of Certification Update, MOC Educational Opportunities and CARE Update
M Herman*[1], W Hendee*[2], R Morin*[3], M Mills*[4] (1) Mayo Clinic, Rochester, MN, (2) Medical College of Wisconsin, Milwaukee, WI, (3) Mayo Clinic, Jacksonville, FL, (4) James Graham Brown Cancer Center, Louisville, KY

The official beginning of the ABR Maintenance of Certification program for medical physicists began this year. Many have registered and many more have questions. The purpose of this session is to present a brief review of the ABR MOC program, its current status and to delve into some of the details related to successfully fulfilling the MOC process. The physics trustees of the ABR will first present a review of the MOC program as it is currently being implemented for medical physicists. The driving forces behind MOC as well as the four essential components of the program, Professional Standing, Lifelong Learning/Self Assessment, Cognitive Expertise, Assessment of Practice Performance, will be reviewed. Examples will be provided in each case to help medical physicists understand the details of the process. The web-based process will be outlined. Specific issues related to individuals who have less than ten years until their certificate expires and to those certified by ABMP will be addressed. The MOC presentation will be followed by presentations from the chair of the ACR Commission on Medical Physics and the Chairman of the American College of Medical Physics, both who will address opportunities and developing programs aimed at providing the essential continuing education credits necessary for each of us to maintain certification.

The final portion of this session will be dedicated to an update on the CARE bill. The Alliance for Quality Medical Imaging and Radiation Therapy (of which both the AAPM and ACMP are members) met again in March 2005 to further develop, in anticipation of passage of the Care Bill, statutes designed to specify the training and experience of all medical professions performing or planning medical imaging and radiation therapy. The Bill, as written, is designed to include both Medical Physicists and Medical Dosimetrists in the proposed regulation. The CARE bill was recently reintroduced in the US congress.
An opportunity to ask questions of the speakers will be provided at the end of the session.
Educational Objectives:

1. To review the current ABR maintenance of certification program
2. To understand the process for all time limited certificate holders
3. To understand mechanisms offered by ACR and ACMP to obtain MOC credits
4. To review the current status and implications of the CARE Bill

Therapy Continuing Education Course Room 6C
CE: Site Specific IMRT Planning - II

TU-E-T-6C-01
Intensity Modulated Radiation Therapy for the Treatment of Breast Cancer
L Burgess*, D Yan, William Beaumont Hospital, Royal Oak, Michigan, William Beaumont Hospital, Royal Oak, MI

Intensity modulated radiation therapy for the treatment of Stage 0, I and II breast cancer has been in clinical use at William Beaumont Hospital since March 1999. The goals of IMRT for breast cancer delivered through static, multileaf collimator segments include optimizing dose homogeneity, avoiding unnecessary normal tissue irradiation and standardizing target volume coverage without significantly increasing the time required to plan and treat patients. The IMRT process can be divided into four different phases, simulation, treatment planning, treatment delivery and quality assurance. During the initial simulation procedure an immobilization device is constructed, level marks are tattooed and the treatment borders are defined. A CT is done in the treatment position in order to define the treatment area as well as delineate normal tissues. In addition to the CT scan the use of MR is becoming a useful tool to define nodal regions of interest. The treatment plan is generated to deliver a homogeneous dose throughout the breast volume and minimize dose to the lungs and in the case of left sided breast patients the heart. The beam arrangement of two tangential fields is adjusted for depth, gantry angle and collimator angle in order to provide full coverage to the breast and lumpectomy cavity with sufficient margin and avoid unnecessary irradiation of normal tissue. The IMRT segments are created based on 5% increments of isodose surfaces; these forward planned segments are then optimized in order to deliver a homogeneous dose throughout the breast volume. The plan is evaluated with respect to percent of breast volume receiving doses in excess of 105% and 110% of the prescribed dose. The treatment process includes patient positioning and setup, electronic portal imaging and treatment delivery. This is accomplished in a conventional treatment time slot of 12 minutes. As part of the overall patient quality assurance patients are imaged everyday for every port during their treatment. On weekly review the physicians have ten images, five medial and five lateral, with which to make clinical treatment decisions as to patient setup and treatment port placement. In addition to patient quality assurance plan quality assurance is assessed by completion of an independent calculation check as well as analysis of treatment delivered to the MapCheck device as compared to the planned treatment. Both the fluence and absolute dose measurements can be analyzed with this system. Using intensity modulated radiation therapy to deliver whole breast irradiation has proven to be an efficient method to deliver uniform dose throughout the entire breast volume which can be seen to reduce the acute and chronic toxicity's associated with radiation therapy for the treatment of breast cancer. Research supported by Philips Medical Systems and Elekta Corporation.

Educational Objectives:
1. To understand the goals and use of IMRT in the treatment of breast cancer.
2. To understand the IMRT process for simulation, planning, treatment and quality assurance in the treatment of breast cancer.

TU-E-T-6C-02
Clinical Implementation of IMRT for Lung Cancers
H Liu*, X Wang, H Murshed, C Stevens, T Guerrero, P Balter, K Prado, Z Liao, J Chang, R Komaki, J Cox, R Mohan, UT M.D. Anderson Cancer Center, Houston, TX

IMRT has not been widely accepted as a standard-of-practice for treating lung cancers because of concerns of organ motion and that IMRT may spread large volume of low dose to radiosensitive lung tissue. At our institution, IMRT has been used mainly in the management of superior

sulcus tumors, mesotheliomas, challenging non-small-cell and small-cell lung cancers, and retreatment situations. To be able to use IMRT effectively for lung cancers, we need to pay attention to the following specific issues unique to this site. Patient Selection: IMRT may benefit patients who have critical organs adjacent to target volumes, e.g. spinal cord, esophagus, and previously irradiated tissues. IMRT can also be a superior tool compared to 3DCRT in providing dose coverage of complex shaped tumors such as multiple primary lesions and lymph nodes, and sculpturing dose away from normal lung. Target and motion: GTV for lung cancers should ideally be defined using multimodality imaging combining CT, PET, and MRI (if involving spinal cord and other soft tissues). CTV margin should consider probability of tumor seeding outside GTV and histology of different diseases. ITV margin should ideally be defined using dynamic 4D imaging to account for patient and tumor specific internal motion mainly from respiration. For highly mobile tumors, breath-hold or other motion mitigation techniques may need to be implemented for IMRT delivered with dMLC. PTV margin needs to be examined and defined based on specific patient setup techniques with the help of portal or on-line imaging. Accurate and reliable patient setup and immobilization are critical to IMRT as any other sites. Inverse planning: The most radiosensitive thoracic structure is lung, which may be affected by even low doses and often competes with target volume in terms of planning objectives. Shaping low doses away from lung is an important priority for lung and unique to IMRT of lung cancers. Providing adequate coverage with sufficient homogeneity to target volume is another important goal in planning. Sparing critical organs, i.e., cord, esophagus, heart, and reducing hot spots in non-specific normal tissues should also be included as planning goals. The number of beams and their angles should be optimized carefully with the goals of sparing lung and critical organs, meanwhile considering delivery efficiency and patient compliance. Use of many equally spaced beams (>7) should be rarely used. Dose delivery and QA: IMRT delivery with dMLC should consider optimizing leaf sequence and improving MU efficiency. MLC transmission and leakage can contribute significant dose to lung and normal tissues for IMRT plans with many segments and high degree of modulation. Dosimetry verification should be performed for each treatment planning system, which is often limited in the degree of dose accuracy and is likely to underestimate low-doses for lung IMRT. Monte Carlo based systems can be used complementary to measurements for commissioning and dosimetry QA purposes.

Educational Objectives:
1. To understand physics processes involved in using IMRT for lung cancers;
2. To understand specific requirements and unique aspects of implementing IMRT for lung cancers.

Therapy Symposium — Room 6E
Training MDs and CMDs

TU-E-T-6E-01
The ASTRO Physics Curriculum
E Klein*, Washington University, Saint Louis, MO

In 2002, the American Society of Therapeutic Radiology and Oncology (ASTRO)'s Radiation Physics Committee appointed an Ad-hoc Committee on Physics Teaching To Medical Residents. The main initiative of the committee was to develop a core curriculum for physics education. The document resulted in a recommended 54-hour course. Some of the subjects were based on American College of Graduate Medical Education (ACGME) requirements (particles, hyperthermia), while the majority of the subjects along with the appropriated hours per subject were devised and agree upon by the committee. For each subject there are learning objectives and for each hour there is a detailed outline of material to be covered. Some of the required subjects/hours are being taught in most institutions (i.e. Radiation Measurement and Calibration for 4 hours), while some may be new subjects (4 hours of Imaging for Radiation Oncology). To ensure that the subject matter and emphasis remain current and relevant, the curriculum will be updated every two years.
Klein EE**,** Balter JM, Chaney EL, Gerbi BJ, Hughes L. ASTRO's Core Physics Curriculum for Radiation Oncology Residents. Int J Radiat Oncol Biol Phys. 2004 Nov 1;60(3):697-705.

TU-E-T-6E-02
ABR Perspective On the ABR Written Exam
E Chaney*, Univ North Carolina, Chapel Hill, NC

Goals of the American Board of Radiology: One of the main purposes of the American Board of Radiology is to certify medical doctors to practice Radiation Oncology in North America. Certification is issued to candidates who meet training requirements and who demonstrate their knowledge and proficiency by successfully completing comprehensive computer-based and oral examinations. The purpose of the computer-based cognitive examination covering physics is to test the candidate's knowledge of the principles of physics underlying the practice of radiation oncology.
Accomplishments: Since 1989 the ABR has awarded 2442 certificates in Radiation Oncology. Between 1934 and 1989, 10,843 certificates were awarded in Radiology, a grouping that included both Diagnostic Radiologists and Radiation Oncologists.
Resources to help physicists know what to teach: The ABR provides information on the certification process at its website (http://www.theabr.org/). Included at this website is a study guide for the cognitive examination. The guide is in the form of a detailed outline of topics covered by the exam.
Upcoming changes: The current study guide is undergoing review and revision. Changes in the content are influenced by a number of sources including changes in Radiation Oncology such as technological advances and obsolescence, training requirements established by the Accreditation Council for Graduate Medical Education, reports and recommendations issued by professional societies and commissions, and federal and state regulations.

TU-E-T-6E-03
MDCB Perspective On "Teaching Physics to Dosimetrists"
I Das*, Univ Pennsylvania, Philadelphia, PA

Goal of the organization or project: The Medical Dosimetry Certification Board (MDCB) provides examination for competency in clinical and medical physics area for dosimetrist. The candidates who pass the examination are called Certified Medical Dosimetrist (CMD). Medical physics education and training curriculum is essential for a good patient care and qualifying the MDCB examination. **Accomplishments:** Since 1988, over 2200 dosimetrist are certified through MDCB examination. There are limited number of medical dosimetry programs that provide training and education. JRCERT accreditation is highly recommended for programs offering dosimetry training. The MDCB popularity has grown internationally. Last year Korea was added as MDCB examination site. Several other countries are being considered for MDCB test sites. **Resources to help physicists know what to teach:** There are nine categories in the examination; radiation physics, dose calculation methods, treatment planning, localization, brachytherapy, radiation protection, quality assurance, professional responsibility and computers with 20%, 25%, 30%, 8%, 5%, 2%, 3%, 2% and 5% questions, respectively. Proper medical physics education and training responsibility rests on medical physicists. A physicist who is planning to teach dosimetry course should visit www.MDCB.org and familiarize with the didactic and training requirements and other valuable information. **Upcoming changes:** The examinations are critically evaluated every year and at a regular interval through strategic planning that was conducted in 2003. The outcome is being implemented in 2005 examinations. Continuing education is being updated to maintain CMD certification. Formal training and accredited programs are given more importance.

TU-E-T-6E-04
The Dosimetry Training Tool (DTT) Project
A Boyer*, S Kaylor, Stanford Univ School of Med, Stanford, CA, Stanford University, Stanford, CA

Goal: A program was funded in 2002 by the NCI to produce and support a web-based computer-aided distant learning tool for training medical dosimetrists. Medical physicists, radiation oncologists, and medical dosimetrists have served as volunteer authors of the 24 modules in the tool consistent with the recommendations of the American Association of Medical Dosimetrists (AAMD) for a recognized medical dosimetry training program. The distant learning modules contain assessment instruments for both the summative evaluation of the students as well as the formative evaluation of the learning tools. The intent of this project is for graduates

from these programs to apply for the certification examination administered by the Medical Dosimetrist Certification Board when they have accrued the required two years of training and experience. **Accomplishments:** The authors have developed and refined their individual modules by electronic transmission of course material to developers at Stanford. Over 7000 html pages are currently online. Medical physicists, radiation oncologists, and medical dosimetrists in radiation oncology centers serve as mentors for the students. A test of the tools is being conducted by 73 mentors registered to train approximately 159 students. **Resources:** Information about the program is available on the web at http: dosimetry.stanford.edu. **Upcoming Changes:** The html pages are being converted to an xml format using a learning management system being developed at Stanford. The project is now recruiting reviewers to participate in a round of revisions of the existing material that will take place over the next year.

Educational Objectives:
1. To understand the goals and methods of a web-based training project for Medical Dosimetrists
2. To learn about opportunities to participate in the development of course content in the project.

Imaging Moderated Poster Session
Exhibit Hall 4A - Area 3
Advances in CT and Tomosynthesis

TU-EE-A3-01

CT Number Accuracy of Simulated Lung Nodules Imaged with a Multi-Detector CT Scanner

M Goodsitt*, H Chan, S Larson, E Christodoulou, J Kim, T Way, Univ Michigan, Ann Arbor, MI

Purpose: To investigate the accuracies of the CT#'s of simulated lung nodules for a QCT technique. **Method and Materials:** Spherical balls of 4 diameters (3.2,4.8,9.5 and 16-mm) and 2 compositions (50mg/cc and 100mg/cc $CaCO_3$) were employed as simulated lung nodules. All were scanned in a liquid water-filled container at the center of a 20-cm diameter water-equivalent-plastic phantom using GE multi-detector CT scanners. A subset of the nodules and some 6.2-mm diameter acrylic balls were also scanned in a simulated lung region within a thorax section phantom that was bolused on both sides with water-equivalent slabs. Based on initial results that showed a significant decrease in the CT# of a nodule when scanned in the thorax section, additional studies were performed with 2 size air cavities at the center of the water phantom. **Results:** The CT#'s of the nodules in water were fairly independent of nodule size (average CT#'s of 50mg/cc=59-66HU and 100mg/cc=108-115HU). The CT# of a 50mg/cc nodule scanned at the center of the water phantom was 66HU in water, 51HU in a 2-cm air cavity and 36HU in a 4.9-cm air cavity. The CT#'s of the acrylic balls ranged from about 79 to 96HU within the lung section and had poor-to-good reproducibility on repeat scans (CT# changes of +19HU, -17HU and 1HU for 3 different balls). **Conclusion:** The CT# of a nodule is highly dependent upon the amount of air or low-density lung tissue near the nodule. We believe this error is due to the assumed all-water composition of the patient/phantom in the scanner's beam hardening correction algorithm. The unusual reproducibility of the CT#'s of nodules in the thorax phantom is likely a combined effect of sub-millimeter air gaps between the phantom sections and variability in helical scanning interpolation. Further studies and possible solutions will be discussed.

TU-EE-A3-02

Exact Fan-Beam Image Reconstruction Algorithm for a Specific Truncation Problem: Asymmetrically Positioned Half-Size Detector

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Purpose: In nuclear medicine imaging, diagnostic x-ray CT imaging, and image guided radiation therapy truncation of the projection data may be present due to patient motion, inaccurate positioning or simply an insufficient detector. For fan-beam geometry, images reconstructed with truncated data suffer sever artifacts when reconstructed with the conventional filtered backprojection (FBP) algorithm. A new exact fan-beam image reconstruction algorithm is developed to solve a special case of the data truncation problem. In this configuration, fan-beam projection data are acquired using an asymmetric detector that covers only half of the field of view. **Method and Materials:** In order to solve this data truncation problem, the newly developed fan-beam image reconstruction algorithm via filtering the backprojection image of the differentiated projection data (FBPD) was employed. This algorithm enables line by line reconstruction in image space. The following observations about this FBPD algorithm are crucial to solve the data truncation problem: (1) for a given point in the backprojection image space, only one projection from each view angle is required to properly construct the backprojection image; (2) for each ray passing through a given image point from one source position, there is a conjugate ray passing through the same point. With truncated data, a 2π full scan is required to reconstruct the whole object, and a ROI reconstruction can be obtained using projection data from less than a 2π full scan. **Results:** Numerical simulations have been conducted using a Shepp-Logan phantom. Images reconstructed from the truncated data for scans of the entire object validate this reconstruction algorithm for the full 2π scan. In addition ROI reconstruction has been validated using projection data from less than a 2π full scan. **Conclusion:** This algorithm enables exact fan-beam image reconstruction from projection data acquired using an asymmetric detector which covers only half of the field of view.

TU-EE-A3-03

Performance of a Bench-Top, Megavoltage CT (MVCT) Scanner Using Cadmium Tungstate-Photodiodes

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Purpose: To evaluate the imaging performance of a prototype fan-beam megavoltage CT (MVCT) scanner in Co^{60} and 6 MV beams. **Method and Materials**: The 80-element detector is fabricated by tiling 8-element $CdWO_4$ (element size 0.275 x 0.8 x 1 cm^3) and photodiode arrays and arranging them on an arc (radius = 110 cm). A precision rotary stage and its control are added to create a third generation CT scanner. The attenuation of Co^{60} and 6 MV beams was measured as a function of solid water thickness, and fit to a second order polynomial to correct for spectral hardening artifacts. A calibration procedure was established to remove ring artifacts caused by the distinctly asymmetric line spread functions at the ends of 8-element blocks. The low contrast resolution (LCR) as a function of dose and object size, the signal to noise ratio (SNR) as a function of dose, and the linearity of CT numbers with density were quantified. **Results:** Throwing away one-ninth of collected projection angles to reduce the dose per image adversely affects the resolution in 6 MV images; however, 15 mm targets at 1.5% level are still visible at 7 cGy. The low contrast target of 1.5% at 6 mm diameter is visible in Co^{60} images at 2cGy. The LCR in the objects stays approximately constant with the dose reduced from 17 to 2 cGy. In general, the contrast decreases as the target diameter decreases. The SNR^2 obtained from a uniform phantom increases linearly with dose (R^2=0.9977). CT numbers as a function of the density show a linear trend (R^2= 0.9923). **Conclusion:** The prototype detector performance is satisfactory to achieve the ultimate goal of this project of creating a focused 2-D MV detector with high detective quantum efficiency such that reasonable LCR at low dose can be obtained in MVCT.

TU-EE-A3-04

Cone Beam CT Imaging Versus Digital Tomosynthesis: A Computer Simulation Study for Comparisons

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Purpose: We used a general-purpose PC cluster to develop a parallel computer simulation model for comparisons between the cone beam CT imaging and digital tomosynthesis with the same image acquisition geometry. **Method and Materials:** Our model incorporates quantum noise, detector blurring, and additive system noise into the computer simulation. Radon transforms formalism was applied to analytically calculate the phantom image projection data which were then used to reconstruct the volumetric images for low contrast performance and image quality studies. Feldkamp algorithm was used in the cone beam CT imaging, while the shift-and-add, filtered backprojection, and optimization based algorithms were used in digital tomosynthesis. We implemented a parallel random number generator based on the Weyl sequence to simulate both quantum and system noise. For digital tomosynthesis, we used

blurring profiles and the artifact spread function (ASF) to quantify the magnitude of the out-of-plane artifacts. We also calculated the noise power spectra to characterize the image quality for cone beam CT imaging and digital tomosynthesis. Some artifacts removal methods and programming optimization techniques were also investigated in this study. **Results:** The test results showed that our parallel random number generator had good randomness quality and can be used in the noise study. The images reconstructed from using the digital tomosynthesis algorithms were worse than the Feldkamp algorithm in the cone beam CT imaging. However, it was possible to remove the out-of-plane blurring in digital tomosynthesis by using some special techniques. **Conclusion:** We had successfully developed a parallel computing technique to simulate quantum noise, detector blurring, and system noise for both cone beam CT imaging and digital tomosynthesis. Several quantification methodologies were used to compare these two 3D imaging techniques.

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TU-EE-A3-05

Scatter Radiation in Digital Tomosynthesis

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Purpose: To investigate the characteristics of scattered radiation and its effects on image quality in digital breast tomosynthesis. **Method and Materials:** A GEANT 4 based Monte Carlo package was used to simulate a rotating target/detector tomosynthesis system. The compressed breast was modeled as a cubic block imbedded with 24 small cylinders of different radii and heights in the central layer. An 11cm air gap between the breast and detector was modeled. The incident photon energy was set to 20 keV to avoid the complexity of beam hardening effects. A primary image and a scatter image were generated for each projection. The gantry was rotated around the breast from –25 degree to 25 degree with a 5 degree increment. Reconstructions of the 3D breast were computed from the 11 projection images using primary x-rays only, and primary plus scattered x-rays. **Results:** The magnitude of scatter radiation does not change very much from one projection to another because the scatter volume does not change. However, the primary radiation detected can be significantly different in different projections due to different path length. As a result**,** scatter to primary ratio is very different for different projection. Even with the 11 cm air gap, scatter to primary ratio was observed to be as high as 0.4 for a 5 cm thick breast. 3D breast images reconstructed from projections with only primary x-rays showed higher contrast than those reconstructed from projections with both primary and scatter. Further evaluation is needed to determine if this reduced contrast can affect tumor detectability. **Conclusion:** Scatter to primary ratio changed significantly from one projection to another and was observed to be as high as 0.4 for a 5 cm thick breast. Tomosynthesis slices showed a moderate decrease in contrast due to scatter.

TU-EE-A3-06

Sub-Millimeter Three Dimensional Ventilation Imaging of Rodent Lungs

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Purpose: To develop a technique capable of generating a high resolution 3D ventilation image in a rat model from a series of CT images. This technique will be invaluable in developing strategies for radiation treatment optimization and characterization of pulmonary disease states. **Method and Materials:** A series of three 150gram Fischer 344 rats were euthanized and intubated. The lungs were equilibrated to ambient pressure, then serially inflated and imaged at approximately 1ml increments. A GE flat panel CT scanner capable of 0.15mm resolution was utilized for image acquisition. A deformable image registration algorithm, utilizing 3D optical flow, was applied to each pair of CT images to map, on a voxel by voxel basis, corresponding tissue elements. The difference in average CT number of a nine voxel region surrounding each pair of mapped voxels was then utilized to compute the change in fraction air per voxel (i.e. regional ventilation). This local ventilation measurement was then superimposed onto each voxel of the CT image to generate a 3D ventilation image. The sum of each voxel's ventilation (i.e. total lung ventilation) was then compared to the change in manually segmented lung volumes between each of a series of twenty-two pair of CT images. **Results:** Visualization of the 3D ventilation images revealed regional heterogeneity of ventilation throughout the lung fields. The images required smoothing by averaging over a 0.75mm cube surrounding each voxel to minimize artifacts. The calculated total lung ventilation compared favorably with the change in manually segmented lung volumes, with a slope of unity, as expected, and a correlation coefficient of R=0.99. **Conclusion:** We have demonstrated a unique method of quantifying regional lung ventilation with sub-millimeter accuracy in a rat model. This model has been developed in order to study lung function and radiation injury.

Joint Imaging/Therapy Moderated Poster Session
Exhibit Hall 4A - Area 4
Image-Guided Localization

TU-EE-A4-01

Clinical Experience with a 3-D Ultrasound Prostate Localization System

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Purpose: 3-D ultrasound localization has been performed for external beam prostate treatments at our institution since September 2001. This poster presents an analysis of the daily shifts for 198 patients and 4855 fractions, and the results of tests performed to assess the system's performance and capabilities under clinical conditions. **Method and Materials:** All patients were treated supine, using a rectal balloon. Each day patients are initially aligned to skin marks placed by comparison of portal images with digitally reconstructed radiographs. An ultrasound image set is acquired using a 3-D ultrasound localization system (Sonarray, Varian Medical Systems), and the patient may be shifted to account for variations in prostate position. Ultrasound images and shifts were stored for every fraction. Additionally, three tests are presented:

• To assess the accuracy of the shifts, 7 patients treated on a helical tomotherapy machine were localized daily using both ultrasound and a megavoltage CT scan.
• To assess the extent of intra-fraction motion, ultrasound localization was repeated after treatment for 6 patients and a total of 29 fractions.
• To assess the inter-user variation in shifts, four experienced operators independently localized 5 patients for 5 consecutive fractions.

Results: The mean daily shift for all patients was 7.4±3.8mm. Comparison of ultrasound to MVCT showed that ultrasound localization improved alignment: the mean ultrasound-MVCT vector was 3.0±1.7mm, compared to 4.8±2.4mm between the MVCT and the skin marks. Intra-fraction motion and inter-user variation were found to be small in comparison with the daily shifts. The mean intra-fraction prostate shift was1.9±1.0mm, and the shift was within the 3mm imaging uncertainty of the system for 25 of 29 fractions. **Conclusion:** Our experience shows that 3-D US localization can be a valuable tool for aligning external beam prostate patients, enabling the use of reduced margins and more aggressive fractionation schedules.

TU-EE-A4-02

Impact of Ultrasound-Guided Patient Setup On OAR Dose in Conformal Radiation Therapy for Prostate Carcinoma

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Purpose: To evaluate the impact of daily ultrasound-guided patient repositioning on bladder and rectal dose in the treatment of prostate carcinoma with conformal radiation therapy. **Method and Materials:** Standard-of-care for the treatment of low and intermediate risk prostate carcinoma currently includes 3D conformal radiation therapy (3D-CRT). During external beam therapy, ultrasound-guided isocenter realignment can be performed daily to correct patient setup for prostate motion (up to 1 cm) relative to bony anatomical landmarks. In this study, five patients with substantial ultrasound-documented inter-fraction prostate motion during

their treatment course were selected. Starting with the original treatment plan, two additional plans were retrospectively generated for each patient. In one set, using the ultrasound documented displacements, organ contours were moved for each fraction, thus simulating positioning with misalignment caused by organ motion if ultrasound guidance were not used. In a second set of plans, the isocenter was shifted, as were the organ contours, simulating realignment based on the ultrasound image. In all cases, the number of planned monitor units was set to those of the original plan. For a given patient, isodose distributions, DVHs and EUDs were calculated for the prostate, bladder, and rectum for each fraction and then combined for each shift condition. **Results:** In all reconstructed plans, there were no substantial changes in dose coverage of the prostate (<0.21 % change in EUD) compared to the original plan. However, in some cases with no realignment, higher dose maxima were predicted in the bladder and rectum, with the consequent EUD for each organ significantly greater compared to the original plan. **Conclusion:** Although fractional organ motions may have little effect on the overall dose delivery to the prostate, the effect on the dose to OARs (rectum and bladder) can be significant if no daily realignment is performed.

TU-EE-A4-03

Daily Localization of Post-Prostatectomy Patients with Combined CT and US Image Guidance

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Purpose: Daily localization of post-prostatectomy patients receiving radiation treatment to the surgical bed is a very challenging task. The anatomy bounding the prostate bed can significantly change from day to day due to rectal and bladder filling. Target localization based on bony anatomy may be inaccurate. Ultrasound (US) localization has potential, but since there is not a well-defined target (i.e., prostate), reliability may be inadequate. In a previously presented study, we compared US alignments with CT alignments, and based on the results we developed a clinical procedure that incorporated the two imaging modalities. The results presented in this work are for the first 30 patients (183 alignments) that underwent IMRT treatment to the prostate bed after the initial study was completed. **Method and Materials:** Prior to the first treatment, each patient was aligned based on a pre-treatment CT scan acquired with the Primatom CT-on-rails (Siemens). US images were then immediately acquired with the BAT system (Nomos) and these images were stored as templates. During subsequent treatments the US template images were used to assist the therapists when performing daily US alignment. The accuracy of the alignments was controlled by CT scans taken once every week. **Results:** The systematic differences between US and CT alignments were: 0.8 mm (lateral), 0.4 mm (AP) and 0.5 mm (longitudinal). Some of these values were statistically significant, but their clinical significance is low. The random differences between the two modalities (one standard deviation) were: 2.9 mm (lateral), 3.3 mm (AP) and 3.0 mm (longitudinal), and average absolute differences were: 2.3 mm (lateral), 2.6 mm (AP) and 2.5 mm (longitudinal). **Conclusion:** These results suggest that: (i) the systematic error of the every-day US alignments is minimized; (ii) the target is fully covered by the PTV margin (8 mm) used at our institution in almost all cases.

TU-EE-A4-04

Inter-Fraction Shape Change When Using An Endorectal Balloon for Radiation Therapy of the Prostate

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Purpose: To investigate inter-fraction shape change when using an air-filled endorectal balloon (ERB) to localize and immobilize the prostate.
Method and Materials: Under an IRB-approved treatment protocol to evaluate the use of endorectal balloons, patients have port films acquired before delivery of the treatment fields. Position adjustments in the AP direction are made based on the comparison of lateral portal images with planning DRRs. After treatment, a left lateral portal image is taken to evaluate setup. Currently an ERB is used for 15 fractions (27Gy) of the total treatment. The anterior wall of the ERB in the left lateral portal images for five patients was contoured, and the results used to estimate inter-fraction shape change. **Results:** The mean position of the ERB wall was within 2mm of its position in the treatment plan for all patients, with a standard deviation of 1.2 – 2.3mm at central axis (CAX). Since the ERB minimizes intrafraction rectum/prostate motion, most of this can be attributed to setup uncertainties or patient motion. The standard deviation of the ERB wall at a point 3cm superior to CAX, corresponding to the superior end of the prostate, was larger at 2.1 – 4.3mm. The total range in the position of the ERB wall (i.e. difference in most anterior and most posterior positions) at CAX and 3cm superior to CAX was 4-6mm and 6-13mm, respectively. These differences indicate some significant inter-fraction shape change. **Conclusions:** Interfraction shape change of the ERB appears to be negligible (s.d. 3cm superior of CAX<3mm) for three patients, but more important (>3mm) for two patients, indicating that some form of image-guided or adaptive radiation therapy may be useful for some patients. Results for more patients will be presented at the meeting.

TU-EE-A4-05

Validation of CT-Assisted Targeting (CAT) Software for Soft Tissue and Bony Target Localization

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Purpose: To evaluate the performance of an automatic CT-to-CT image registration algorithm for both soft tissue and bony targets. **Method and Materials:** CT-Assisted Targeting (CAT) software was developed for on-line CT-guided radiotherapy using a CT-on-rails system. The algorithm was tested in two phantom studies and cross-compared with other radiotherapy imaging techniques available in the same room. A BAT phantom (North American Scientific, Chatsworth) was intentionally shifted and imaged each time by (1) an electronic portal imaging device, (2) ultrasound, and (3) the CT-on-rails. A Rando pelvic phantom with imbedded gold markers for target localization using the ACCULOC™ software (Northwest Medical Physics Equipment) was also used. To test the software in patient images, 15 prostate cancer patients receiving 3 CT scans per week over 8 week's treatment were selected. The prostate was chosen as the soft tissue target and a bony structure in the pelvic region (excluding the femoral heads) was used as the bony alignment target. A total of 366 treatment-day CT images were registered using the CAT software and verified by a single observer. **Results:** The phantom studies demonstrated that the CAT software can achieve sub-millimeter accuracy in detecting the intended shifts and were generally agreed well with other established imaging modalities in this controlled phantom study. The CAT software also performed well in patient's CT images. The failure rate, as defined by greater than 3 mm differences between the automatic detected positions and the final positions adjusted by the human observer, was only 2.1 % for soft tissue target registration and 1.6% for bony target registration in 366 CT images. The automatic registration takes less than 12 seconds. **Conclusion:** We have designed a highly robust, accurate, and fast computer algorithm for CT-to-CT image registration. The software provides a quick and reliable application for CT-guided radiotherapy.

TU-EE-A4-06

Accuracy and Precision of Implantable Radiofrequency Transponder Localization Measurements Conducted Using Multislice CT

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Purpose: Accurate localization and monitoring of prostate position during radiation therapy is critical for the precise and safe delivery of dose-escalated treatments, but is challenging due to substantial internal-organ motion. A novel method for tracking prostate position using implantable radiofrequency markers has been developed by Calypso® Medical. An important consideration for these transponders is localization accuracy using computed-tomography (CT) imaging. We evaluated the accuracy and precision of transponder localization using multislice CT scanning. **Method and Materials:** A tissue-equivalent pelvis phantom with three implanted transponders and external alignment markers was used. The relative transponder positional accuracy was 0.1mm, while the positional accuracy of the transponders relative to the phantom surface was 0.5mm. The phantom was placed on a computer-controlled linear stage and multiple scans were acquired using a Philips Brilliance 16-slice CT scanner, varying the detector size, slice thickness, and pitch. Scans were

repeated with the phantom moved 0.5mm longitudinally between scan acquisitions to assess position-measurement accuracy at different locations within a reconstructed CT slice thickness. The transponders were identified and localized on the reconstructed CT images automatically using in-house image processing software. **Results:** The mean error of the transponder localization was less than 0.4 mm in anterior-posterior and lateral-medial directions, and increased to 0.8mm in longitudinal direction primarily due to the uncertainty introduced in the initial slice identification. The predicted longitudinal shift between each consecutive scan followed the actual shift amount accurately with a mean error of 0.014mm and a standard deviation of 0.08mm. **Conclusion:** Our investigations have demonstrated the high accuracy of the transponder localization using a multislice CT scanner. The initial results indicate that the accuracy of such a system is sufficient for prostate localization and position monitoring in clinics. **Conflict of Interest:** This work is supported in part by Calypso® Medical

Therapy Moderated Poster Session
Exhibit Hall 4E - Area 1
Brachytherapy Clinical Applications

TU-EE-A1-01

Accuracy of Clinical Dose Delivery in IOHDR Brachytherapy

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Purpose: To investigate the accuracy of clinical dose delivery in intra-operative high dose rate (IOHDR) brachytherapy. **Method and Materials:** The IOHDR brachytherapy treatments of 10 patients recently treated at our facility were reconstructed. Treatment geometries reflecting each clinical scenario were simulated by a phantom assembly with no added buildup on top of the applicator. EDR2 radiographic film placed at the prescription depth recorded dose distributions for each clinical case. The treatment planning geometry (full scatter surrounding the applicator) was subsequently simulated for each case by adding bolus on top of the applicator and radiographic film was again exposed at the treatment depth. After careful determination of the film's H&D curve, absolute dose distributions in the plane of the prescription depth were evaluated for both scatter environments in each clinical case. **Results:** For the geometries simulating the treatment planning conditions of full scatter, the average dose measured at the treatment depths was within 2% of the prescription and dose distributions were in excellent agreement with the respective treatment plan. However, for the geometry simulating treatment conditions (no added scattering material above the applicator), the dose at the prescription depth was on average 11% lower (range 8-14%) than prescribed. An analysis of the delivered dose distributions and treatment plans shows a resulting average decrease of 2 mm (range 1.2–2.4 mm) in prescription depth. **Conclusion:** Dosimetry calculations for IOHDR brachytherapy are typically done with treatment planning systems with dose calculation algorithms that assume an infinite scatter environment around the applicator and target volume. We have shown that this assumption leads to dose delivery errors which result in significant foreshortening of the prescription depth. It may be clinically relevant to correct for these errors by augmenting the scatter environment or, preferably, by appropriately modifying the prescription dose entered into the treatment planning system.

TU-EE-A1-02

Common Dosimetry Errors in Cervix Patients Treated with Brachytherapy On Clinical Trials

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Purpose: The mission of the Radiological Physics Center (RPC) is to assure NCI and the Cooperative Groups that institutions participating in clinical trials deliver radiation doses that are clinically comparable and consistent. Records of patients treated with brachytherapy on a cervix trial were reviewed for completeness, consistency with the protocol, and dosimetric accuracy. Independent dose calculations were performed at points A, B, vaginal surface, bladder and rectum. **Method & Materials:** The RPC reviewed 271 HDR and LDR implants. Doses were calculated to points A, B, bladder, rectum and the vaginal surface as defined by the protocol in accordance with ICRU-38. The vaginal surface was defined as a point lateral to the center of the source(s) at the surface of the ovoid. RPC doses were compared to the institution's reported doses. **Results:** Dosimetry dose reporting errors were discovered in 78% of the implants. Most errors resulted from incorrectly defining calculation points. For example, point B frequently was measured from the tandem rather than midline of the patient. Other errors were caused by planning only the first implant and not subsequent implants. **Conclusion:** Points A, B, bladder, rectum and vaginal surface have been defined in publications, but a significant percentage of the community incorrectly calculates doses at these points. These reporting errors lead to inconsistencies in reported doses for the trial.

This work was supported by PHS grant CA 10953 awarded by NCI, DHHS.

TU-EE-A1-03

Comparison of High Dose Rate (HDR) Vs Intensity Modulated Radiation Therapy (IMRT) for Prostate Boost Treatment

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Purpose: The objective of this study is to compare dosimetric characteristics of prostate treatments using HDR brachytherapy and IMRT technique. **Method and Materials:** Five HDR patients were selected for IMRT planning. Patients underwent ultrasound guided catheter placement for HDR. CT images were obtained and imported into the Nucletron PLATO Brachytherapy system. The prostate, urethra, bladder and rectum were contoured on axial slices. The dose was calculated and optimized by graphical optimization. The CT images of these structures were exported from the PLATO to Eclipse workstation for IMRT planning and comparison. For each patient, the DVH of HDR and IMRT plans were generated, drawn on the same scale and compared. **Results:** In IMRT plans the DVH curves for PTV dropped sharply and reached to zero volume of the prostate at about 6.4 Gy. In HDR plans the DVH curves for PTV showed a long tail up to a very high dose. About 10% of the PTV for prostate received greater than 12 Gy (200%) of the prescribed dose (6 Gy) in HDR plans. In contrast, the same volume in IMRT plans received less than 6 Gy (100%). Average prostate V90 and V100 dose was about 6.3 Gy and 4.12 Gy respectively for HDR, and 6.09 Gy and 5.74 Gy for IMRT plans, respectively. UrethraV90 dose for IMRT plans showed similar levels (93%), whereas in HDR the dose varied widely (60 to 100%). In all plans, the dose to the bladder and rectum was significantly lower in HDR than in IMRT plans. **Conclusions:** HDR brachytherapy may reduce normal tissue toxicities in prostate boost treatments, even though the dose homogeneity inside the PTV is far worse than in IMRT treatments. Another advantage of HDR over IMRT is that the organ motion is not a significant concern as in IMRT.

TU-EE-A1-04

Development of a Customizable Neural Network Brachytherapy Nomogram Equivalent

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Purpose: The objective is to develop a software brachytherapy nomogram equivalent. Although modern techniques obviated much nomogram usage, situations arise where nomograms prove useful. If site dimensions are unknown, they can be measured followed by nomogram treatment planning. Regulatory agencies mandate independent checks. Deploying this software could easily meet this requirement. A graphical nomogram is fixed and cannot be modified. In contrast, the nomogram equivalent is configurable. This field-customizable tool should further empower clinicians. **Method and Materials:** The nomogram equivalent is a three-layer feed-forward neural network (NN). The inputs consist of three site dimensions and volumes. The hidden layer has ten processing elements (PE's). The output layer is a single PE representing air kerma strength. The PE inputs are weighted, summed and applied to the sigmoid function, defining the PE output. A training algorithm based on differential evolution was developed. A group of fifty competing NN's are

continuously evolved by simulating biological evolutionary processes. The weights are initially assigned random values. During training they are evolved to decrease the error between the NN output and desired value. Training data consist of three dimensions, volumes and air kerma strengths from past implants. The software cycles through the training data, altering the weights. The sum-of-squares difference between the outputs and air kerma strengths drives the training process. Once trained the NN can predict air kerma strengths for new implants. **Results:** The differential evolution training algorithm successfully determined NN weights for predicting required air kerma strengths. In most cases the network predicted air kerma strength within 11 percent. Consistent training data representing the full range of possible implant site dimensions and volumes are important for obtaining accurate predictions. **Conclusion:** The software is ready for clinical use. The authors believe that the NN paradigm is a sound method for implementing a field-customizable nomogram equivalent.

TU-EE-A1-05

External Beam Radiotherapy Boosts to Reduce the Impacts Caused by Edema in Prostate Permanent Seed Implants

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Purpose: In prostate permanent seed implants, it has been shown that edema caused by the surgical procedure decreases dose coverage and hence may reduce treatment efficacy. External beam boosts can be utilized to neutralize the negative impact of edema so that originally desired treatment efficacy can be achieved. This study is to investigate the number of fractions needed in these external beam boosts. **Method and Materials:** The reduction in treatment efficacy can be characterized with an increase in tumor cell survivals and biomathematical models have been developed to calculate the tumor cell survival increases in seed implanted prostates of different edema sizes and durations. A linear quadratic radiobiological model was used to derive the number of fractions needed in the external beam boosts with which the tumor cell survival fractions will be reduced to the desired levels. Prostate edema of different durations and sizes was taken into consideration in tumor cell survival fraction calculations.
Results: As edema duration and size increased, the fraction number needed in the external beam boosts increased for both ^{125}I and ^{103}Pd seed implants. For edema of same duration and size, the needed number of fractions was higher in ^{103}Pd implants than in ^{125}I implants. External beam boost is needed for all the edemas investigated in ^{103}Pd implants while in ^{125}I implants the boost can be avoided for edemas of relatively short duration (3 days) and sizes (less than 20%). **Conclusion:** In conclusion, fractionation sizes have been determined for the external beam boosts that are needed to neutralize the negative impacts caused by edema in both ^{125}I and ^{103}Pd prostate seed implants. The number of fractions needed is larger in ^{103}Pd implants than in ^{125}I implants. The fractionation sizes are also influenced by various radiobiological parameters, and these influences increase as edema size increases.

TU-EE-A1-06

Transrectal Fiducial Carrier for Radiographic Image Registration in Prostate Brachytherapy

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Motivation: Intraoperative dosimetric optimization of TRUS-guided prostate brachytherapy implants requires localization of seeds relative to prostate[1], for which radiographic fiducial-based registration of fluoroscopy and TRUS seems appropriate[2,3]. It is critical to mount the fiducials rigidly and stabilize the prostate, because TRUS and fluoroscopy are sequential and the moving TRUS probe may dislocate the prostate. Transrectal approach provides the shortest distance to the implanted seeds and prostate, thereby maximizing registration accuracy. **Method and Materials:** A precision-machined transrectal sheath containing fiducials is mounted rigidly on the stepper and wraps around the TRUS probe. It mechanically decouples the prostate from the TRUS probe and thus stabilizes the prostate. Acoustic impedance, wall thickness, and diameter were optimized. Acoustic coupling is maintained by circulating liquid gel. The system is depressurized during probe motion. Two embodiments accommodate various types of radiographic fiducial markers. A closed 360-degree sheath of 30mm diameter was developed for conics that are extremely robust to segmentation and image distortion, being mathematically invariant to projective transformation. A partial 180-degree sheath was developed for straight lines and point fiducials that are computationally simpler to localize but inherently less accurate. The sheath connects to a commercially available TRUS stepper. **Results:** Phantom and in-vivo canine tests were performed. Prostate motion and sheath stability were quantitatively analyzed with volume CT by tracking both structures and implanted markers while the TRUS probe was retracted by 5mm increments. With the sheath in place, prostate and sheath both were stationary in CT imaging and the fiducials did not interfere with the TRUS image. Excellent acoustic coupling was achieved during probe motion with acceptable degradation of ultrasound image quality.

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Therapy Moderated Poster Session
Exhibit Hall 4E - Area 2
Clinical Measurements II

TU-EE-A2-01

Determination of Output Factors for Small Photon Beams

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Purpose: Due to the strong field size dependence and differences in response of different detectors, the determination of output factors for small fields is still ambiguous. By means of careful measurements and a sophisticated analysis of the values, the uncertainty was minimized. **Method and Materials:** For beams of 6 and 10 MV collimated with the Elekta Beam Modulator the output versus field size was measured with different detectors. Field sizes were from 4*4mm² to 160*210mm². An analytical curve comprising a sigmoidal part for the primary dose and an asymptotic exponential for the scatter part was fitted to the measured values: $D = P_{\infty}\frac{r^n}{k^n + r^n} + S_{\infty}\left(1 - e^{-br}\right)$. The ratios with respect to the ionization chamber measurement for large fields (>50*50mm²) were linearly extrapolated. The measured values for small fields were corrected with these ratios. **Results:** The measured data could be fitted very well with the proposed function. The statistical uncertainty was small enough to clearly demonstrate the differences of the different detector signals. For large fields the slope of an unshielded mini diode was highest, followed by the MOSFET and the Pinpoint chamber curves. The diamante detector, the shielded diode and the 0.125ccm chamber showed approximately the same slope of the output function. Due to their size, the chambers measured a too low output at field sizes below 20*20mm². The other detectors agreed within 5%. Correcting with the sensitivity ratio this spread could be reduced to 1.6%. **Conclusion:** A physically meaningful function was proposed and successfully tested, to describe the photon output for all field sizes. The Pinpoint chamber is not suitable for small field measurements. For the MOSFET we used the signal was too noisy. All other detectors give the same output down to field sizes of 4*4mm², if the proposed correction is performed. The shielded Si-diode may be used without further correction.

TU-EE-A2-02

Effect of Respiratory Motion On the Delivery of Breast Radiotherapy Using Physical Compensators and SMLC Intensity Modulation

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Purpose: This study evaluates the effects of respiratory motion on breast radiotherapy delivered using physical compensators and sMLC intensity

modulation. **Method and Materials:** An anthropomorphic breast phantom was constructed of polyethylene plates between which radiographic films are inserted. The phantom is mounted on a moving platform which simulates one-dimensional sinusoidal oscillation with variable amplitude and frequency. The respiratory motion effect of three breast radiotherapy techniques was evaluated, including sMLC IMRT (Corvus TPS), custom-designed physical compensators, and aperture based IMRT. The treatment plans for the latter two techniques were generated using an in-house TPS. Film comparisons were performed to check experimental reproducibility and evaluate the effects of respiratory motion. **Results:** Subtraction residues between two films measured under identical experimental conditions are well within 5%, which is within the uncertainties in experimental setup and dosimetric technique. The largest motion-induced differences occur at the posterior field edge where high dose gradients exist. This is due to dose blurring effects and does not depend on the delivery technique. The subtraction residue in the remainder of the treatment region is within 7%, with the exception of the apex of the breast in the Corvus IMRT plan. A virtual bolus region is created during Corvus planning to allow expansion of the intensity map outside of the skin contour. This region of "flash" is given an electron density of zero. The anterior hot spots observed in the Corvus plan are thought to result from the high intensity delivered to this virtual bolus region. **Conclusion:** This work indicates that respiratory motion induced dose variations are generally less than about 2%, which is not considered clinically significant. However, further investigation is warranted to assure that the dose to the apex of the breast is not excessive when using the virtual bolus method to provide flash for Corvus IMRT plans.

TU-EE-A2-03

Evaluation of Dose Calculation in KV-Cone Beam CT Data Sets

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Purpose: The accuracy of dose calculation in CT data sets derived from a linac attached kV-cone beam CT (kV-CBCT) equipment was analyzed by comparing dose profiles, depth dose curves, and dose volume histograms of scanned objects with the dose parameters calculated in the respective fan beam CT cubes. **Method and Materials:** To perform kV-CBCT acquisition for adaptive radiotherapy an x-ray tube and a flat panel imaging detector were attached at a linac on opposing sides of the isocenter. Several phantoms, namely a water filled cylindrical phantom, a special contrast phantom with several inlays of different materials, and an Alderson head phantom were scanned. Furthermore a kV-CBCT was performed for a real head and neck patient with the intention to correct for patient setup-errors. The data were reconstructed with an in-house software tool not executing any scatter corrections. Dose distributions were calculated using a clinically approved pencil beam algorithm for modulated or actual treatment plans. Attenuation coefficient to electron density conversion for kV-CBCT dose calculation was done with help of the contrast phantom using a simple calibration procedure. Dose contours and DVHs were compared to reference calculations on fan beam CT data. Additionally a γ-criteria analysis was performed. **Results:** For all analyzed cases absolute dose values and DVHs calculated on the CBCT data sets were in good agreement with the reference data and no differences greater than 3% were found in the considered profiles. Therefore the comparisons also passed the 3% and 3mm γ-criteria in nearly all voxels. **Conclusion:** Although CBCTs may hardly be comparable in image quality to standard diagnostic ones they might nevertheless be good enough for a sufficiently accurate dose calculation and therefore be well suited for dose guided radiotherapy. Even better results may be possible by additionally including scatter correction. **Conflict of Interest:** Supported by Siemens-OCS.

TU-EE-A2-04

Helical Tomotherapy Leakage Radiation Half and Tenth Value Layers in Concrete and Lead

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Purpose: According to NCRP Report 51, if the leakage TVL is not measured, the primary radiation TVL should be used for the shielding design. Varian measured its own 90º leakage TVL in 1995. To determine which TVL value is most suitable for Hi-Art II Tomotherapy, its leakage radiation half and tenth value layer in concrete and lead are measured. **Methods & Materials:** Film dosimetry is used to identify the high leakage region on the Hi-Art II Tomotherapy machine. The entire surface area of the machine was covered with Kodak XV2 films. After identifying the high leakage region, an ion chamber was used to measure the leakage. The ion chamber (Exardin A12) was placed near the high leakage region, and located 1.13m above floor level and 2m away from the radiation isocenter. To allow for enough build up for high energy photons a 1cm bolus was added to the existing ^{60}Co buildup cap. The leakage radiation was measured by adding blocks of concrete and lead in front of the ion chamber. The exposure data was recorded using a PTW Unidose electrometer. The half and tenth value layers of concrete and lead were calculated. All measurements were obtained under normal treatment conditions (800 MU/min, 360° rotation) for a period of 7 minutes. **Results:** The measured leakage radiation HVL and TVL values of the Hi-Art II helical Tomotherapy machine are 0.011m (0.44") and 0.044m (1.74") in lead, and 0.066m (2.61") and 0.282m (11.11") in concrete, respectively. **Conclusion:** The leakage radiation TVL in concrete and lead obtained for Hi-Art II helical Tomotherapy machine are close to published data for 90 degree leakage radiation of Varian (1995), but significantly lower than the NCRP (1997) data for primary radiation.

TU-EE-A2-05

Measurements of Dose Averaged LET Distributions in Lateral Direction in Water Using CR-39 for Collimated Carbon Ion Beam

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Purpose: In order to develop more precise dose averaged LET calculation algorithm on the basis of the pencil beam algorithm (PBA) for carbon ion radiotherapy, we have to calculate depth and lateral dose averaged LET distribution for the pencil beam. Particularly, since the lateral dose averaged LET distribution is formed by scattered particles and fragment particles, we expected the distribution is somewhat complex. In this study, we focused on the lateral dose averaged LET distribution. Lateral dose averaged LET distributions were measured using CR-39 LET detector and analyzed. **Method and Materials:** Carbon ion irradiation was carried out using the horizontal beam line at Heavy Ion Medical Accelerator in Chiba. A therapeutic carbon beam with energies of 290 MeV per nucleon (MeV/n) was used. Using a CR-39 solid state track detector, lateral dose averaged LET distributions in water were measured at various depths for collimated mono-energetic beam. **Results:** We analyzed etch pits on the CR-39, and lateral dose averaged LET distributions in the region of penumbra were obtained. As a result, their LETs in even penumbra region were about constant at each depth. **Conclusion:** Lateral dose averaged LET distributions in water were measured at various depths for collimated mono-energetic beam using a CR-39 solid state track detector. It was obvious that their LETs in even penumbra region about constant at each depth. We found that lateral dose averaged LET can be calculated roughly using depth dose averaged LET for broad beam.

TU-EE-A2-06

Patient Setup Accuracy and Precision of Prostate Radiation Treatment with BrainLab ExacTrac X-Ray System with Implanted Fiducials

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Purpose: To confirm the intra-radiation treatment motion of the prostate is small enough so that daily positioning of the prostate is a valid effort. To test the automatic target alignment of the ExacTrac X-ray® system. **Method and Materials:** The target positioning data of 51 radiation treatment sessions were collected retrospectively from 5 prostate cancer patients treated with IMRT between June and August in 2004. All patients were in supine treatment position and immobilized with HipFix (Med-Tec, Inc.) without any padding or mold on the couch. Four gold fiducial markers (ϕ1.2 mm, 3.0 mm long, Med-Tec, Inc.) were implanted in the patient's prostate under ultrasonic guidance prior to the planning CT scan. Prior to the treatment, fiducials were localized using stereoscopic kV x-ray imaging system (ExacTrac X-ray®, BrainLab) and the couch was automatically shifted to a correct the target position. There are two sets of data collected. 1) pre-treatment target deviation after the automatic positioning with kV x-ray images. 2) post-treatment target deviation. **Results:** 1) The average

pre-treatment deviations of the target after the automatic positioning were –0.2 ± 1.3 mm (vertical), -0.1 ± 1.0 mm (longitudinal), and 0.0 ± 0.4 mm (lateral). 2) The average isocenter shifts (difference of the target positions between pre- and post-treatment) were –0.2 ± 1.0 mm (1SD for all errors, vertical), -0.3 ± 1.2 mm (longitudinal), and 0.1 ± 0.5 mm (lateral). **Conclusion:** Both averages of post-treatment shift and pre-treatement deviation of the target were negligible considering the uncertainty. Both results showed lower positioning uncertainty by half in the lateral direction compared with the vertical and longitudinal directions, which suggest the lateral target motion was restricted better than the vertical and longitudinal. Same magnitude of position uncertainty of the pre-deviation and post-shift indicates the limit of the precision of daily ExacTrac's automatic positioning.

Imaging Moderated Poster Session
Exhibit Hall 4A - Area 3
Image Processing, Visualization, and Display

TU-FF-A3-01

Automating Data Processing for Image-Guided Adaptive Radiotherapy

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Purpose: To facilitate the adaptive radiotherapy process by automating the flow and processing of data required to accurately transfer, integrate and accumulate information such as tissue boundaries and computed doses between serial 3D and 4D patient imaging studies. **Method and Materials:** Specific tasks in the data flow for adaptive radiotherapy have been implemented as independent software components that can be instantiated on a single computer or across a network. These components include data access, rigid and deformable image registration, data mapping, and dose accumulation. The data access component retrieves and pushes information to and from a variety of data stores and the other components. The image registration component supports various transformation models (affine, thin-plate spline and B-splines) and intensity-based similarity metrics (sum of squared differences and mutual information) and can handle both global and limited field of view registrations. Required initialization steps are handled using site specific protocols and data-driven image processing. A generalized transformation representation was developed to ensure interoperability with other processing components. The data mapping component operates on geometry and voxel-based information such as tissue boundaries, computed doses and image volumes. The dose accumulation component accommodates different re-sampling and summing schemes. The flow of data from one step is sequenced using simple top-down data flow or a script-based sequencer. **Results:** A flexible system that automates many of the steps involved in adaptive radiotherapy has been implemented. This system has been used to map and integrate dose and geometric information from a variety of image studies (serial and 4D CT, multimodality data) and clinical sites (brain, lung, liver, prostate). **Conclusion:** Automation of data processing to support the adaptive radiotherapy process is possible for a wide variety of clinical sites and imaging situations. This automation should make more widespread adoption of adaptive radiotherapy possible.

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TU-FF-A3-02

Two Male Tomographic Models Segmented From MR and CT Images

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Purpose: To develop two new tomographic models of Korean typical adult males from magnetic resonance (MR) and computed tomography (CT) images of living subjects, and to calculate photon dose conversion coefficients for external irradiation geometries. **Method and Material:** Two healthy volunteers, subject A (172 cm in height, 65 kg in weight) and subject B (172 cm in height, 68 kg in weight), whose body size was within the range of Korean average values (170.9±3.7 cm in height, 67.9±4.8 kg in weight), were recruited. Whole body MR images were obtained from one subject and CT images from the other. The source images were semi-automatically segmented to construct three dimensional matrices. The resulting matrices were ported into Monte Carlo transport code, MCNPX2.4, and photon dose conversion coefficients for external monoenergetic photon beams with the energies from 0.015 MeV to 10 MeV were calculated for idealized irradiation geometries. **Results:** The resulting Korean tomographic models were named KTMAN-1 and KTMAN-2. Up to 80% of organs and tissues in both models were within 30% of average values of Korean adult male. 21 and 23 organs and tissues were segmented in KTMAN-1 and KTMAN-2, respectively. Dose conversion coefficients were computed for all organs and tissues in external irradiation geometries: antero-posterior (AP), postero-anterior (PA), right lateral (RLAT), and left lateral (LLAT). Through investigation of differences in organ doses between tomographic models and stylized model (ICRP74 data), unrealistic position of thyroid, testes, arms, and stomach in stylized models were revealed. **Conclusion:** Two new tomographic models constructed in this study provided more realistic dose conversion coefficient than stylized models. Although difference of organ mass and position between the Korean models and western reference model caused insignificant discrepancies of organ doses for external dosimetry, the Korean models will be more meaningful for internal dosimetry.

TU-FF-A3-03

Automatic Method of Bone and Static Tissue Removal in Neuro CT Angiography

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Purpose: The purpose of this study was to optimize a post-processing algorithm to eliminate density from bone or other tissues that remain constant during a contrast enhanced CT angiography procedure without compromising the detection of small lesions. **Method and Materials:** Five patients were scanned using a standard brain CTA protocol: kv=120, mA=300, thickness=2.5 mm, interval=1.25 mm, contrast volume=75 cc's, delay=12s). An identical acquisition was obtained prior to contrast injection. To eliminate movement related errors, the data sets were aligned using a standard motion correction algorithm within SPM2. The pre-contrast data were used to form a mask based upon intensity thresholds that would capture bone (>200 HU). Additional image processing was used including smoothing and morphologic operations to improve the removal of the bone signal while minimizing the effects to vessel signal. The optimization process involved successive erosion and dilation operations on the mask. A filter was used on the mask to zero pixels between the skull and the external boundaries of the mask. Subtracting the pre-contrast data from the post-contrast data was performed to remove static signal. The bone mask was then applied to the difference data to create the final image. The post-processed CTA data were transferred to a 3D workstation for viewing and qualitative assessment which included the source images and maximum intensity projections. **Results:** Bone subtraction was successful in all patients without qualitatively significant degradation in contrast-to noise. The clinical data shows it is possible to remove non-vascular signal without compromising the visualization of small aneurysms. **Conclusion:** An automatic method to remove bone density from brain CTA data sets was developed. The method requires a pre- and post-contrast CTA acquisition and thus increases the patients overall radiation exposure though not to significant levels. The automated method will reduce workload and provide non-biased angiographic data for clinical review.

TU-FF-A3-04

Impact of Room Illuminance On Black Level Luminance and Contrast Detection for Off-Axis Viewing On High Resolution Normal and High-Bright Flat Panel Displays

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Purpose: Flat panel display image quality is known to be highly dependent on viewing angle. The contribution of room illuminance to black level luminance is well understood for CRTs, but, is not clearly understood for flat panel displays. We have investigated the effect of room illuminance and off axis viewing on displayed image quality. Two high resolution 9.2 megapixel flat panels were evaluated under various room illuminance levels and viewing angles – a standard IBM T221. **Method and Materials:** Black level luminance was measured at 0, ±15, ±30 and

±45 degrees with room illuminance levels of 0, 2, 5, 10 and 50 lux. Luminance was measured with a Minolta LA-100a spot meter and illuminance levels were measured with an International Light Luminance Meter IL 1400a. The luminance target (3% of total display area) was centered on the display. Reader studies using a computer generated contrast detail phantom were conducted at each viewing angle and room illuminance level. Five readers read the target images. Specular reflections were minimized for all measurements and reader observations. **Results:** Minimization of specular reflections in the viewing room minimized the change in measured black level luminance. As room illuminance levels increased and viewing angles became more acute black level luminance increased. Reader results are presented as k-values and a correlation with room illuminance and black level luminance is demonstrated. The optimal viewing condition was shown to be 0 degrees with a room illuminance of 2 lux. Substantial degradation of measured k-value and black level luminance occurred at other viewing conditions. **Conclusion:** Visual perception of small targets is substantially impacted by both viewing angle and room illuminance. The results of these measurements help to explain the observed variations in 5 and 50 lux data presented at the Pittsburgh AAPM meeting.

TU-FF-A3-05

A Novel Algorithm for Spatial Noise Compensation in IBM''s 9.2-MP LCD: A Fuzzy Classification Approach

A Poolla*, J Suri, Fischer Imaging Corporation, Denver, CO

Purpose: This paper presents a new fuzzy-pixel classification algorithm to compensate spatial noise in LCD displays. **Method and Materials:** Our noise compensation technique was tested on 30 images acquired using the CCD camera. We measured the MTF and NPS parameters before and after the compensation. The compensation protocol is as follows: displaying a uniform test pattern with known digital value on the LCD display; acquiring the image (640 x 480 pixel size) of the displayed pattern using CCD camera; bi-cubic down-sampling the image to 64 x 48 pixel size; use the optimized fuzzy-pixel classification algorithm to detect the noisy pixels and obtain a mask of the noisy pixels; applying noise compensation on the raw image using the noisy mask; applying Gaussian smoothing on compensated image; display the compensated image on the LCD display for MTF and NPS measurements. **Results:** The results demonstrate that overall mean of the *vertical MTF* is higher than that obtained using the conventional method. Also the overall mean of the *vertical NPS* is lower using the fuzzy compensation technique. The peaks in the *horizontal NPS* are lower and less wide compared to the non-compensated NPS. The vertical MTF and NPS have improved using the noise compensation technique, and horizontal NPS is almost comparable in compensated and non-compensated images. **Conclusion:** We developed and demonstrated a new fuzzy-pixel classification algorithm for noise compensation in LCD displays. The compensated algorithm shows an MTF improvement of 5.6% when compared with non-compensated case. A very similar trend was observed in the horizontal and vertical NPS plots. We can conclude from the above-presented results that the fuzzy-pixel classification algorithm is effective in detecting the pixels contributing towards the noise of the image. In future, if images are processed before display to compensate for spatial noise of the LCDs, diagnosis efficiency can be increased.

TU-FF-A3-06

A Novel Algorithm for MTF/NPS Measurement for LCD/CRT Characterization and Its Evaluation: A Directional-Based Approach

J Suri*, A Poolla, Fischer Imaging Corporation, Denver, CO

Purpose: This paper presents an improved strategy for MTF and NPS measurements based on neighborhood approach, unlike the conventional approach. **Method and Materials:** Since resolution (MTF) and noise (NPS) are important quantitative measures of image quality, our protocol characterizes the displays using these parameters. The novelty of our evaluation strategy lies in the way we compute our MTF. This involves computation of MTF in eight different directions from its central position, averaging them and then replacing it at its central location. Such a method is a directional-based MTF, and offers advantage of taking neighborhood pixels. **Results:** It is observed that the directional MTF is higher than the conventional MTF. Hence, directional-based MTF approach presents a better method of computing the MTF. This also is justified by saying that the noise is being averaged by considering the directional approach. A similar behavior is observed for the NPS of the two displays. The noise observed in the NPS curves of the LCDs can be attributed to the discrete pixel structure of the LCDs. CRTs in this aspect have lower noise compared to the LCD displays. But the higher MTF of the LCDs indicates that LCDs have higher resolution, which is an important physical property for mammography applications. **Conclusion:** Based on the experimental results we conclude the following: **(a)** Our algorithm demonstrated the measurement of MTF using directional approach was considerably higher than the conventional approach; **(b)** LCDs and CRTs have a larger MTF difference using directional-based approach compared to conventional approach; **(c)** All the measurements show that MTF and NPS curves obtained using directional-based approach are consistent and smooth; **(d)** All the MTF measurements using directional-based approach are better for LCDs compared to the conventional CRTs.

Joint Imaging/Therapy Moderated Poster Session
Exhibit Hall 4A - Area 4
4D and Real-Time Image Guidance

TU-FF-A4-01

Respiratory-Gated Dual Fluoroscopic Imaging for Positioning and Verification

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Purpose: To improve the setup and verification of respiratory-gated treatments that use an external surrogate to track tumor motion. **Method and Material**: A system was designed to perform respiratory-gated dual fluoroscopic imaging either before or during treatment. The Varian RPM system is used to track the breathing signal, which is used to turn on and off two x-ray generators and acquire simultaneous fluoro from two directions. The operator can select between three operation modes: ungated fluoro controlled by the foot pedal, gated fluoro controlled by the foot pedal, and continuous acquisition of gated fluoro. **Results:** We have built a working prototype of this system, and have conducted early tests on phantoms. We have found that a gated fluoro system should include radiographic or fluoro capture capabilities, automatic and manual control of imaging, and on-line monitoring tools. Dual imaging allows 3D verification of gated treatment when implanted fiducial markers are used. **Conclusion:** Respiratory-gated radiation treatment has a great potential to increase the dose conformality for patients with large intrafractional tumor motion. When using an external surrogate to track the motion, the position of the internal anatomy relative to the surrogate can be verified using respiratory-gated fluoroscopy. For many applications, gated fluoro is superior to ungated fluoro because the imaging dose is reduced, data storage requirements are reduced, and on-line analysis is simplified. **Conflict of Interest:** This research was supported by Varian Medical Systems.

TU-FF-A4-02

Active Tool/Fiducial Segmentation and Tracking in Multiple Modalities

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Purpose: To build a tracking framework that, given a description of a tool/fiducial, the geometry of the imaging system and a sequence of images, outputs estimates of selected kinematics of the tool/fiducial along with a measure of the uncertainty in these estimates. The output of the system may be used as feedback to actively modify the imaging system parameters in order to achieve the desired precision with which the object is tracked while minimizing other parameters (eg. dose delivered to the patient). **Method and Materials:** A two stage approach is employed where (i) the object is segmented using its invariant features, its model, and other prior information that may be available and (ii) a particle filter is applied to the results of the segmentation for robustly tracking the object. A particle filter is chosen because of its simplicity, its robustness to noise and occlusion, its ability to represent multimodal beliefs, and also because its

performance approaches that of the optimal Kalman filter given enough samples. **Results:** This approach has been applied to a (physically) simulated brachytherapy procedure to track the position of a needle loaded with seeds in an X-ray fluoroscopic sequence. The system outputs the 3D position and orientation of the needle along with a confidence measure along each dimension. This output is robust to noise and partial occlusion. **Conclusion:** This work provides a generic framework for segmentation and tracking across multiple modalities that also reports a confidence measure for each estimated parameter. Such a system has many online applications such as radiation therapy guidance, intra-operative image-guided laparoscopic surgery, brachytherapy and various biopsy procedures.

TU-FF-A4-03

Concept and Evaluation of Averaged 4-D CT Imaging in Determining the Internal Target Volume for Extracranial Stereotactic Radiotherapy of Lung Nodules

R Drzymala*, J Liu, C Hampton, J Bradley, Washington University School of Medicine, St. Louis, MO

Purpose: To evaluate the accuracy and robustness of averaging 4-D images to determine the internal target volume (ITV) for small lung tumors during breathing. **Method and Materials:** A Philips Brilliance 16-slice CT simulator (CT-sim) obtained axial cinematographic (cine') images (512x512 pixels, 480mm FOV) of a phantom that moved with known distance and velocity in both the longitudinal and axial planes. The CT-sim recorded 25 cine' images in each of 16 slices, 1.5mm thick to create a 24mm slab of data at different times during a motion cycle. The images at each slice position were averaged to produce composite slices. Composite slices were assembled longitudinally to produce a composite slab. Concatenated composite slabs are called an Averaged 4-D (4-D_{Avg}) image set.

Patients were scanned using the protocol above. Gross tumor volume (GTV) appearing in the 4-D_{Avg} image set was contoured to produce an mGTV (ITV minus the margin for sub-clinical disease) before superposition on beam's-eye-view DRRs and transferred to an on-line electronic portal imager (EPI) for comparison of the mGTV position to that of the GTV as observed during treatment. **Results:** Phantom measurements showed key factors which govern the ability of the 4-D_{Avg} image set to accurately represent the location of objects during motion: slice thickness, cine' duration relative to the period of motion and the sampling frequency of the cine' relative to the duration of motion at its extremes. We determined the position of objects undergoing a 0.2Hz movement over 20mm to within approximately 1.0mm. Similar results were obtained for a patient in the stereotactic body frame using an EPI. **Conclusion:** For tumors with motions having a frequency about 0.2Hz over a 20mm range, one can obtain positional accuracy within approximately 1mm using the 4-D_{Avg} technique outlined above. **Conflict of Interest:** Partly funded by Elekta, Inc., Norcross, GA.

TU-FF-A4-04

Target Volume Definition by 4D CT Imaging and Temporal Projections

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Purpose: To develop a fast method for the definition of intra thoracic target volumes by 4D CT imaging, temporal projections as well as interactive visualization and drawing. Furthermore, to evaluate the utility of the method in the context of respiratory correlated and gated treatments. **Method and Materials:** After retrospectively gated 4D CT scanning, a 4D dataset comprising three-dimensional datasets corresponding to different phases of the breathing cycle is reconstructed. For the purpose of respiratory correlated or gated radiation treatments, after visual assessment of the magnitude of the lesion motion with respect to the respiratory signal, a subset of the 4D dataset is collapsed/projected in the time dimension with user selectable transfer function. Some sensible choices are maximum intensity or average value projections. Then, for a particular 2D slice, the user defines a target contour on the composite temporal projection image. Upon completion of the drawing, cine loop is played through time for the particular slice. If corrections are necessary, the cine is stopped: the user browses through the various time points of the particular 2D slice and adjusts the contours. Once the adjustments are completed, the target definition process continues with the next slice. **Results:** The proposed method was implemented in a software prototype and evaluated for several datasets. In comparison to the scenario of drawing target volumes on temporally sequential 3D datasets, the proposed method reduces target definition times by a factor of 5 to 10. **Conclusion:** A fast and efficient method has been developed for the definition of intra thoracic target volumes to be used in the planning of respiratory correlated or gated radiation treatments. **Conflict of Interest :** Research supported by Siemens.

TU-FF-A4-05

Feasibility of Tracking Wireless AC Electromagnetic Transponders in Head and Neck Cancer Environment

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Purpose: Precision setup is essential for head and neck IMRT due to the steep dose gradients used. A new device called the Calypso® 4D Localization System (Seattle, WA) has been developed which is capable of performing objective, real-time target tracking during radiation. This system is based on non-ionizing AC electromagnetics that utilizes small wireless Beacon® transponders, and could potentially be used to localize transponders embedded in a mouthpiece as a method to track skull movement during head and neck irradiation. Because AC electromagnetics can be influenced by nearby conductive metals, the effect of dental restorations, such as amalgam, on transponder localization accuracy was studied. **Method and Materials:** A dental prosthesis was casted from a volunteer. 16 of 28 prosthetic teeth were filled with standard dental amalgam. Three transponders set in a fixture were placed under the detection array and baseline measurements of each transponder's x, y and z coordinates away from the array were obtained. Next the prosthesis was placed immediately posterior to the transponders, simulating a worst-case scenario of nearby amalgam. Each transponder's coordinates from the array were re-measured. The transponders coordinates in the presence of the prosthesis were compared to the baseline measurement without the prosthesis. The experiment was repeated with transponders up to 20 cm away from the detection array. **Results:** Results showed that the presence of amalgams had no measurable effect on the system's capability to localize multiple transponders at distances up to 20 cm from the array. **Conclusion:** This investigation demonstrates the potential of wireless AC electromagnetic technology embedded in a mouthpiece to enable accurate and continuous tracking of the skull during head and neck IMRT. **Conflict of Interest:** Work supported by Calypso Medical Technologies; Authors Mate, Zeller, Eidens and Vertatschitsch have a financial interest in Calypso Medical.

TU-FF-A4-06

Dynamic Accuracy of An Implanted Wireless AC Electromagnetic Sensor for Guided Radiation Therapy; Implications for Real-Time Tumor Position Tracking

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Purpose: A wireless tumor localization and tracking system using three implanted AC electromagnetic transponders is in clinical trials for use in prostate cancer (Calypso® Medical). Phantom-based studies have shown sub-millimeter spatial localization accuracy in static tests. Accuracy has not been evaluated for dynamic motion found in lung tumors. This study was designed to determine the feasibility of using this patient positioning system for real-time tumor-tracking. **Materials and Methods:** A 4-dimensional (4D) stage capable of arbitrary multidimensional motion with speeds up to 10 cm/sec was constructed. Two elliptical trajectory paths were created with peak-to-peak motion of 1cm x 2cm x 1cm and 2cm x 4cm x 2cm in the x, y and z directions. Each trajectory was operated with periods of 15 - 20 cycles per minute. The Calypso System was operated using one and two transponders with radiofrequency signal integration times of 33 ms 100 ms. The transponders were mounted on the 4D-stage, with the ellipse centroids positioned 14 cm from the array. The effects of ellipse size, speed, number of transponders and signal integration time on transponder localization accuracy were evaluated by comparing the intended and measured trajectories. **Results:** The root mean square (RMS)

position difference was less than 1 mm for all tested combinations. While small, the RMS error was largest for the large ellipse at 20 cycles per minute compared with the small ellipse at 15 cycles per minute. The single-transponder system with 67 ms integration time had the smallest overall error, with a maximum single-point error of 1.3mm. **Conclusions** Use of a wireless electromagnetic implanted transponder system for real-time tumor-tracking is feasible, with RMS errors less than 1mm for high-speed multidimensional ellipses. This compares favorably with continuous fluoroscopic tracking methods without an ionizing radiation burden. This work is currently being expanded to patient-derived tumor trajectories.

Therapy Moderated Poster Session
Exhibit Hall 4E - Area 1
Monte Carlo Validation

TU-FF-A1-01

An Investigation On the Impact of Incident Fluence Prediction On the Computed Doses

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Purpose: For IMRT, most dose calculation algorithms modify the incident energy fluence by a scalar transmission matrix which represents the radiation transmitted through the moving multi-leaf collimator (MLC). These matrices inherently exclude the effects of beam hardening by the MLC and only approximate the radiation scattered from the MLC. The purpose of this study is to determine how such approximations effects patient doses distributions in the limit of a realistic transmission matrix (TM). **Method and Materials:** Monte Carlo (MC) dose calculations were utilized in this study. The reference calculation utilized full MC transport through the moving MLC during the dose computation. The test calculation employed a realistic TM, determined by scoring the ratio of the incident and transmitted energy fluence through the MLC from the reference MC simulation, during the patient dose calculation to include the effects of the MLC on the patient treatment. Ten head-and-neck dynamic IMRT patient treatment plans were computed with each method and dose indices were compared. Dose indices used in the evaluation included the GTV D_{98}, CTV D_{95}, Brainstem D_{02}, Cord D_{02}, and Parotids D_{50}. **Results:** For each target index studied, the maximum deviation observed was ≤-1.5% of the treatment dose. The TM dose calculation systematically underestimated the full MC target dose by ~1%. The local differences between the dose indices for the cord and the brainstem were within ±2.4%. Local dose differences of up to 2.9% were observed for the parotid D_{50}. **Conclusion:** When a realistic transmission matrix is used, patient local dose results in the targets differ by ≤1.5% of the treatment dose computed with full MC dose simulations, justifying the use of such matrices for both MC and other dose calculation algorithms for the cases studied. This work is supported by NIH-1R01CA98524.

TU-FF-A1-02

Commissioning Fast Monte Carlo Dose Calculation for Lung Treatment Planning

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Purpose: To commission a commercial Monte Carlo (MC) simulation package, NXEGS (Numerix LLC), for photon beam dose calculations. We investigated within NXEGS the EGS4 compatibility mode, fast MC, and post processing (PostP). **Method and Materials:** We commissioned NXEGS and Pinnacle 6.2b with the same set of measured data. We compared its dose calculation accuracy and efficiency with the collapsed cone convolution algorithm in Pinnacle and the National Research Council EGS4. Dose distributions were compared in three phantoms: a water phantom to check the output and beam profiles; a water phantom with a lung slab to test the inhomogeneity correction; and a water phantom with 1-3 cm diameter cylindrical air pockets to test the PostP algorithm. We also compared fast MC using PostP with Pinnacle for a three-field lung treatment plan. Number of histories is chosen to give +/- 2% dose accuracy at the isocenter. All doses were converted to cGy per MU.
Results: Fast MC improves computational speed by a factor of ~10 from the EGS4 compatibility mode. PostP decreases number of histories required and hence the computation time by another factor of ~10. PostP adds ~1 minute per 10^6 dose voxels. Inside the lung slab, fast MC with PostP differed from Pinnacle by ~0.03cGy/MU with a misalignment of ~2mm whereas fast MC with PostP agreed within 0.03cGy/MU of EGS4. PostP did not preserve the dose perturbation from ≤1cm air inhomogeneities.
Conclusion: Without PostP, the accuracy and computational time scaled with number of histories. When we specify ±2% accuracy in the target volume, the dose calculation time using fast MC with PostP is comparable to Pinnacle for a three-field lung plan. NXEGS fast MC with PostP predicts the dose spread due to electron transport in lung with good accuracy-to-speed ratio and is suitable for routine treatment planning.

TU-FF-A1-03

Comparison of Tumor Control Probability and Lung Complication Probability for Lung Cancer Treatment with and Without Heterogeneity Correction

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Purpose: To compare the tumor control probability (TCP) and lung complication probability (LCP) for lung patients planned with and without heterogeneity correction.
Method and Materials: Twenty-one previously treated lung cancer patients were selected for the TCP and LCP comparison. The treatment plans were initially generated with a commercial treatment planning system. The dose calculations were recalculated using Monte Carlo simulations in homogenous and heterogeneous geometry rebuilt from patient CT data and using identical beam parameters. A linear quadratic model was used for the TCP analysis. A modified parallel quantal model was used for the LCP calculation. Dose volume data from the Monte Carlo results were used as input for the TCP and LCP calculations.
Results: Although the dose calculated for 50% of the target (D50) in heterogeneous geometry is slightly higher than the dose in homogeneous geometry, TCP with heterogeneity correction is significantly lower than that without heterogeneity correction due to the existence of cold spots. For 8 patients with similar prescription doses, the average TCP falls from 97% in homogeneous geometry to 72% in heterogeneous geometry. The LCP is similar for heterogeneous geometry and homogeneous geometry: the difference is less than 2% although the LCP is slightly higher for heterogeneous geometry because of the slightly higher dose.
Conclusion: The outcome for lung treatment may be compromised by inaccurate dose calculation (without the use of heterogeneity correction). Cold spots in the target volume are the major cause for the lower TCP for lung plans recalculated with heterogeneity correction. In some cases, the beam shape and/or field size can be modified to remove such cold spots. Our results suggest that heterogeneity correction is necessary for lung cancer treatment planning to ensure adequate target coverage and dose uniformity.

TU-FF-A1-04

Determining Parameters for a Multiple-Source Model of a Linear Accelerator Using Optimization Techniques

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Purpose: To determine the parameters of a multiple-source model for an arbitrary linear accelerator using optimization methods. **Method and Materials:** A multiple-source model describing the energy fluence output of a linear accelerator was developed in this study. A point source modeled radiation from the target, a finite-size source all extra-focal radiation, and an electron source contaminant particles. The parameters determined were the mean energy curve (for off-axis softening), intensity profile curve (for non-uniform photon energy fluence), electron source values, extra-focal source size, energy, and intensity. The parameters were optimized by minimizing the gamma error between the dose calculation results and the beam data measurements by applying a non-linear optimization technique not requiring gradient information. The dose was calculated by an algorithm based on superposition/convolution of Monte Carlo determined scatter kernels. The beam data measurements required were depth dose curves, lateral profiles, and diagonal profiles for multiple field sizes. The model requires minimal data about the internal dimensions and construction of the accelerator head. **Results:** The method was applied to 231 realistic data sets of varying quality and consistency for Elekta, Siemens and Varian

accelerators. The gamma error (1%, 3 mm) for an average optimized model was lower than 1.0 for 98% of the measurement points. Typical duration of the optimization to derive the model parameters was 5–15 minutes. In cases where the measurements contained inconsistencies, the resulting gamma errors were significant, which indicates that the method could be useful in quality assurance of measurement data. **Conclusion:** This study demonstrated that the parameters for a multiple-source model can be determined in an efficient and stable manner using optimization methods. The model is applicable to an arbitrary accelerator and has clinically acceptable accuracy and execution time. **Conflict of Interest:** This work was supported by Varian Medical Systems.

TU-FF-A1-05

Limitations of the Photon and Electron Transport Algorithms in GEANT4 for Radiotherapy Applications

E Poon*, F Verhaegen, McGill University, Montreal, QC, CA, McGill Univ Health Center, Montreal, QC, CA

Purpose: To examine the limitations in the photon and electron transport algorithms in GEANT4, so as to identify its suitability for radiotherapy applications. **Method and Materials:** A set of simulations were performed to access the accuracy of GEANT4. We calculated depth dose distributions of photon and electron beams incident on a water phantom, and examined the effects of dose perturbation in the presence of a lead interface. The results are compared to the EGSnrc Monte Carlo code. We attempt to provide explanations for the differences observed. An investigation of the problems in the condensed history algorithm is done through a series of cavity simulations under Fano conditions. **Results:** In homogeneous water, the depth dose distribution of a 10 MeV incident electron beam depends on the electron step size limitations and secondary particle production thresholds. The disagreement with BEAMnrc is over 4%, which is partly due to differences in cross section data among the EM models. For incident photon beams of 400 keV and 6 MeV, GEANT4 agrees with EGSnrc to within 0.4% and 2% respectively beyond the depth of dose maximum. Larger differences are found in the buildup regions due to problems in electron transport. In a Pb/water geometry, we observe an underdose of up to 84% upstream of the interface for a 100 kVp beam. This is mainly due to the neglect of spin effects in electron elastic scattering. In the Fano cavity simulations, problems in electron step and boundary crossing algorithms result in an underestimation of cavity dose by up to 39%. Accurate cavity response can be obtained using severe step size restrictions. **Conclusion:** GEANT4 is unsuitable for simulations where electron disequilibrium exists. Improvements in boundary crossing and backscattering are needed, and spin effects should be modeled.

TU-FF-A1-06

Monte Carlo Based Retrospective Dose Calculations for Outcomes Modeling

P Lindsay*, I El Naqa, A Hope, J Bradley, M Vicic, J Deasy, Washington University, St. Louis, MO

Purpose: To improve the dosimetric accuracy of archived lung treatment plans, we use a novel Monte Carlo recalculation method based on pencil beam optimization methods. The impact of the dose corrections on outcome modeling of pneumonitis was assessed. **Method and Materials:** For 189 archived non-small cell lung cancer plans, dose distributions were re-calculated using the VMC++ Monte Carlo code (I.Kawrakow). Nominal input spectra for 6 or 18 MV photons were used; only radiation transport through the patient was modeled, using each patient's pre-treatment CT scan. We derived approximate beam weights and wedge effects with a novel method based on optimization of MC-derived pencil beams: MC and treatment planning results were matched for the water-based (non-heterogeneity corrected) results. Heterogeneity-corrected plans were then produced using Monte Carlo with the derived beam profiles and weights. **Results:** The method showed good agreement when compared against a small series of treatment plans using a convolution-superposition dose calculation. For the lung plans, the average absolute differences in metrics of interest (V20, maximum lung dose, and mean GTV dose) between water-based TPS and water-based MC data were 0.5%, 0.9 Gy, and 0.8 Gy; for water-based TPS versus heterogeneity-corrected MC data the absolute differences were greater: 2.0%, 1.8 Gy, and 2.5 Gy (typically heterogeneity corrected dose distributions produced higher dose values). The correlations between V20 and occurrence of pneumonitis for water-based TPS, water-based MC, and heterogeneity corrected MC data were (using Spearman's rank correlation coefficient) 0.13, 0.13, and 0.14 (respectively). For maximum lung dose, the correlations were 0.15, 0.14, and 0.09. **Conclusion:** The differences in some metrics (e.g., maximum lung dose) between water-based and heterogeneity corrected data may have a significant impact on modeling treatment outcome. This method could be applied to any multi-institutional data sets for which RTOG format plan archives are available.

Therapy Moderated Poster Session
Exhibit Hall 4E - Area 2
Photon Planning and Techniques

TU-FF-A2-01

A Heterogeneity Inclusive Algorithm for Calculation of Central-Axis Absorbed Dose in Finite-Size Pencil Beams

R Pino*, P Nizin, Baylor College of Medicine and The Methodist Hospital, Houston, TX

Purpose: To develop algorithms for calculating central-axis absorbed dose from high-energy photon beams in heterogeneous media of arbitrarily varying density. **Method and Materials:** We employ and extend a phenomenological model for the central-axis absorbed dose in therapeutic photon beams (Nizin, Med. Phys. **26**, 1893-1900 (1999)) in order to describe absorbed dose in heterogeneous media. The parameters defined by the model are extracted from beam data for a homogeneous water phantom. For heterogeneous media, the model's parameters are determined by rescaling these for water using the local values of the relative density of the medium. **Results:** The phenomenological model was generalized for arbitrarily varying density media by introducing a differential equation that modulates the field size dependent normalization factor. This factor is multiplied by the photon fluence, which decays exponentially with the radiological depth. The generalized model was tested using slab geometries where layers of water and lung-like material alternate. We found very close agreement between absorbed dose calculated using the generalized model and Monte Carlo simulations (Kawrakow et al, NRCC PIRS-701 (2003)) for finite-size pencil beams and for a wide range of field sizes for broad beams. **Conclusion:** Accurate algorithms for calculation of central-axis absorbed dose in heterogeneous media are proposed. For both narrow and broad photon beams, the model generates results that are in close agreement with Monte Carlo data for slab geometries. **Conflicts of Interest:** This research was supported by NOMOS Radiation Oncology Division of North American Scientific.

TU-FF-A2-02

Beam-Weight Optimization for the Field-In-Field Treatment-Planning Technique Using Fuzzy Logic

P Petti*, UC San Francisco, San Francisco, CA

Purpose: The field-in-field treatment-planning technique is commonly used in tangential-field irradiation of breast cancer, but it can also applied to other sites, eliminating the need for wedge filters in the treatment plan. The purpose of this work is to investigate an efficient and reliable method that employs fuzzy logic to optimize the beam weights for treatment plans that utilize the field-in-field treatment-planning strategy. **Method and Materials:** Three tumor sites were considered, one in the breast, one in the brain, and one at the skull base. Four beam segments were used for the breast plan, and 8 segments were employed in the brain and skull-base plans. The Pinnacle^3 treatment-planning system was used to design the beam apertures in all cases. The dose per monitor unit (MU) delivered by each beam separately, calculated at a selection of points within the target volume using the Pinnacle^3 planning system, served as input to the optimization procedure. In the optimization process, relative cold- and hot-spot volumes within the target were defined as fuzzy variables. Development of a fuzzy rule set to determine how to adjust the number of MU delivered through each segment was simplified by dividing the target volume into sub-volumes associated with each beam segment. The change in the number of MU was a fuzzy variable, which was de-fuzzified using the center-of-mass method. **Results:** The field-in-field plans developed using fuzzy logic were comparable to standard plans employing wedges developed by experienced dosimetrists. The fuzzy optimization was also fast, requiring only seconds to complete. For both the fuzzy-optimized and

standard plans, the relative cold-spot volume within the target was between 0 and about 6%, and the hot-spot volume was less than 1%. **Conclusion:** Fuzzy optimization theory can be successfully applied to optimize the beam weights for field-in-field treatment planning.

TU-FF-A2-03

Effects of CT Calibration On Tissue Inhomogeneity Correction in Radiotherapy

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Purpose: To quantify the effect of CT calibration on tissue inhomogeneity correction in radiotherapy. **Method and Materials:** Materials with known electron densities relative to water ranging from 0 to 2.34 were scanned with two GE Light Speed CTs at the four available KVs of 80, 100, 120 and 140 KV and a GE 9800 CT. The effect of using mismatched calibration curves on calculation of tissue inhomogeneity corrections were evaluated using the effective TMR method. **Results:** All CT calibration curves agree with each other between air and water region. Above the density of water, the calibration curves for lower kV were significantly higher than those for higher kV, by up to 560 HU for cortical bone (ρ_e= 1.69). Thus, using a generic calibration curves would lead to an error in the determination of electron density and hence the tissue inhomogeneity correction. The effect of CT number error (ΔHU) on dose calculation is approximated as

$$\Delta D/t\ [\%/cm] = TMR' * \Delta HU/2000, \text{ for HU} > 1000,$$

where t is the physical thickness of the dense material layer and TMR′ is the TMR gradient. For example if a cortical bone is scanned with GE Light Speed at 80 KV but the CT calibration curve of 140 KV is used in dose calculation and the treatment radiation beam is the 6 MV at field size of 1x1 cm^2, the dose calculation error down stream of the bone layer will be about 1.2% per cm of bone. The effect is smaller for the 18 MV beam due to the smaller TMR gradient. **Conclusion:** For best accuracy of tissue inhomogeneity correction, the KV specific, instead of a generic, CT calibration curve should be used.

TU-FF-A2-04

Geometric Parameter Analysis to Predetermine Optimal Radiosurgery Technique for the Treatment of Arteriovenous Malformation

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Purpose: To develop a method of predicting the values of dose distribution parameters of different radiosurgery techniques for treatment of arteriovenous malformations (AVM) based on internal geometric parameters. **Method and Materials:** For each of eighteen previously treated AVM patients, four treatment plans were created: circular collimator arcs, dynamic conformal arcs, fixed conformal fields and intensity modulated radiosurgery (IMRS). An algorithm was developed to characterize the target and critical structure shape complexity and the position of the critical structures with respect to the target. Multiple regression was employed to establish the correlation between the internal geometric parameters and the dose distributions for different treatment techniques. The results were used develop a statistical model which predicts the values of dose distribution parameters based on internal geometric parameters. The model was applied to predict the dosimetric outcomes of different radiosurgery techniques and select the optimal radiosurgery technique for a random AVM patient. **Results:** Several internal geometric parameters showing statistically significant correlation ($p < 0.05$) with the treatment planning results for each technique were identified. The target volume and the average minimum distance between the target and the critical structures were the most effective predictors for normal tissue dose distribution. The structure overlap volume with the target and the mean distance between the target and the critical structure were the most effective predictors for critical structure dose distribution. When the model was applied to a random patient, the predicted treatment results were in close agreement with the original data. **Conclusion:** A statistical model has been described which successfully predicts the values of dose distribution parameters of different radiosurgery techniques and may be used to determine the optimal technique on patient-to-patient basis.

TU-FF-A2-05

The Dosimetric Stability of the Prostate and Critical Structures in the Presence of Internal Motion for An Adaptive Correction Strategy

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Purpose: An adaptive correction strategy has been proposed in which internal motion is corrected for by repositioning the MLC aperture as an alternative to the current practice of patient repositioning. The study purpose was to investigate the dosimetric stability of this strategy in the presence of internal motion. **Method and Materials:** Internal motion shifts were introduced in 25 prostate plans by shifting the PTV, rectum and bladder contours with respect to the bony-anatomy. Thirty-six randomly selected isotropic displacements of magnitude 0.5, 1.0, 1.5 and 2.0 cm were sampled for each patient, totaling 3600 errors. The adaptive correction strategy, which shifted the beams-eye-view of the MLC aperture to match the contours, was used to correct each of these errors. Recomputed plans were compared to the original treatment plans via dose–volume histogram analysis. Changes of more than 5% of the prescription dose were deemed clinically significant. **Results:** The adaptive correction strategy produced small dose discrepancies for all structures considered apart from the femoral heads. Coverage of the PTV was excellent: D_5, D_{95} and D_{mean} where changes were <5% for all of the 3600 simulated internal motion shifts. D_{33} of the rectum was increased by >5% in 9/3600 sampled internal motion shifts, while the bladder D_{20} deviated by >5% in 9/3600 samples. The femoral heads D_{mean} increased by >5% for 651/3600 (18%) internal motion shifts. However, D_2 was not increased by >5% for any of the internal motion shifts. **Conclusion:** These data demonstrate the robustness of the proposed adaptive correction strategy for correction of internal motion. The corrections can be performed remotely, thus eliminating errors resulting from increases in treatment time or from patient repositioning. This method has the ability to correct for both interfraction displacement of the prostate and for intrafraction prostate motion.

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TU-FF-A2-06

The Use of MVCT Images for Dose Calculation in the Presence of Metallic Objects

S Meeks*, K Langen, T Wagner, T Willoughby, P Kupelian, M. D. Anderson Cancer Center Orlando, Orlando, FL

Purpose: Metallic objects such as dental fillings and prostheses cause artifacts in kilovoltage CT (kVCT) studies. The problem with these artifacts is twofold. Firstly, they obscure soft tissue structures. Secondly, the artifacts create artificial CT numbers that compromise the accurate calculation of absorbed dose. Megavoltage CT (MVCT) imaging reduces these artifacts, and this study investigates the impact of such artifacts. **Method and Materials:** The MVCT to electron density curve for a Hi-ART II helical tomotherapy unit was extended to include high electron density materials using aluminum, titanium, and copper targets. MVCT images of a prostate patient with a hip prosthesis that is treated on a helical tomotherapy unit are then used to evaluate the impact of kVCT artifacts on the calculation of absorbed dose. At the time of treatment planning the kVCT image was used for planning. For actual patient treatment the artificial hip was generously contoured and no beam entrance though this region was allowed for treatment planning. Daily MVCT image of the patient were acquired for patient alignment. Retrospectively, a treatment plan was generated that allowed beam entrance through the hip prosthesis. This second plan was recalculated on the MVCT image to determine the dosimetric effect of the artifacts. **Results:** The recalculated dose in the MVCT image shows that the absorbed dose in the hip prostheses and immediately next to the prosthesis is lower in the MVCT image than in the kVCT image. This dose differential can be as large as 15%. Soft tissue areas that are affected by the kVCT image artifacts have higher absorbed dose in the MVCT based recalculation. **Conclusion:** In the presence of metallic artifacts, significant differences in the absorbed dose computation exist between dose calculations based KVCT images and that calculated in megavoltage images.

WEDNESDAY, JULY 27

Imaging Continuing Education Course Room 618
CE: Breast Imaging Physics and Technology - III

WE-A-I-618-01
Recent Advances in Digital Mammography
M Yaffe*, Imaging Research Program, Sunnybrook & Women's HSC, Univ Toronto, Toronto, ON, CA

Purpose: To familiarize the participants with new developments and applications related to digital mammography. **Method and Materials:** The ACRIN DMIST results are about to be released and it is expected that a benefit will be demonstrated in terms of the accuracy of digital mammography relative to film mammography. Further technical development in acquisition and display technology will improve the efficiency with which digital mammography can be performed. Additional and possibly larger benefits are likely to come from new applications, including computer-assisted detection and diagnosis (CAD), tomosynthesis, telemammography, contrast imaging, interventional procedures and risk assessment. These will all be made possible or facilitated by the precise acquisition of mammographic images in digital form. For example, CAD can improve the accuracy and consistency of mammographic interpretation by emulating a second reader. Telemammography can improve access to high-quality mammography in underserved areas. The problem of reduced accuracy due to the complexity of overlying fibroglandular tissue structures in the dense breast can be addressed by tomosynthesis, which simplifies the image by reconstructing individual tomographic slices. Alternatively, imaging of the effects of tumor angiogenesis can be accomplished by subtraction techniques using intravenous contrast media. This can not only improve conspicuity of lesions, but also better reveal the extent of disease. The risk of breast cancer is highly associated with mammographic density. By quantifying density, risk can be estimated and strategies for screening optimized. In the future, tracking of density may have a role in breast cancer prevention by providing a method for monitoring interventions designed to reduce risk. **Conclusion:** The benefits of digital mammography are likely to extend in several important directions. **Conflict of Interest:** Martin Yaffe's laboratory has collaborative research agreements with GE Healthcare and with Fischer Imaging on topics related to digital mammography. Dr. Yaffe also conducts research with R2 Technologies and is on the Scientific Advisory Board of XCounter and ART.

Imaging Continuing Education Course Room 617
CE: PET Physics and Technology - III

WE-A-I-617-01
PET/CT Attenuation Correction and Image Fusion
J Carney*, University of Tennessee, Knoxville, TN

PET/CT scanners provide intrinsically co-registered CT and PET images in a single scan session, which can then be viewed together as a fused image showing both anatomy and function. This in particular allows for excellent localization of features in the PET image. Furthermore, with the CT scan performed prior to the PET scan, routine attenuation correction of the acquired PET data is possible. The use of CT images for this purpose in PET/CT scanners has the advantages of shorter scan times and effectively noiseless transmission images as compared to the transmission scans that are used in standalone PET cameras. This does however require the non-trivial step of transforming the CT images to 511 keV attenuation images that are reprojected to obtain the desired attenuation correction factors. This lecture will describe the use of CT images for attenuation correction in PET/CT scanners and address the advantages and challenges of this procedure and the use of fused images in the clinical environment. Improved attenuation correction procedures to take account of different kVp settings in the CT protocol, as well as the particular challenges in emerging applications such as cardiac PET/CT will be addressed.

Educational Objectives
1. Review the principles of attenuation correction in PET and the implementation of this procedure using CT images in PET/CT imaging.
2. Understand the particular challenges of CT-based attenuation correction, including the choice of respiration protocols and other problems of patient motion, the use of CT contrast agent, and the presence of foreign objects in the body.
3. Review the advantages of image fusion in PET/CT, and the clinical challenges of registering the CT and PET imaging modalities that remain, such as respiration.

Imaging Continuing Education Course Room 609
CE: Digital Imaging Systems, Processing, Analysis and Display - III

WE-A-I-609-01
Digital Image Processing in Radiography
D Foos*, X Wang, Kodak Research Laboratories, Rochester, NY , Eastman Kodak Company, Rochester, NY

Digital radiography systems are capable of capturing a wide range of x-ray exposures in a single image. The wide latitude of these capture devices dictates that images are digitally processed before display. Attempting to directly print or display the full dynamic range of the captured image will result in an image with low contrast that is unacceptable for diagnostic interpretation. Image processing algorithms are used to identify the range of exposures (represented as code values) that correspond to the diagnostically relevant regions, followed by a rendering process to transform signal values in the diagnostically relevant regions to display values. The image processing algorithms need to perform these steps completely automatically, or with a minimum amount of human intervention, to facilitate technologists' workflow. Image processing performance is ultimately gauged by the ability to automatically and consistently generate images of diagnostic quality.

Recognition of the diagnostically relevant exposures consists of segmentation of the collimation, direct exposure, and anatomy regions. This is a challenging computer-recognition problem because several factors cause the characteristics of the image, and corresponding code value histogram, to vary. These factors include the body part and projection, exposure technique, collimation, use of anti-scatter devices, use of contrast media, etc. Robust segmentation will also automatically recognize other features such as prosthetic implants, pacemakers, and left-right markers. Once the image is properly segmented, the signal values for the diagnostically relevant regions are transformed into values for display. Rendering the region of interest for display generally consists of establishing the image grayscale rendition, and signal equalization and contrast enhancement, which is based on spatial frequency decomposition and reconstruction. Because of the tremendous flexibility to render images to different aims, understanding the rendering preferences of radiologists is a critical component of digital radiography image processing. Establishing the aim appearance for different exam types, then adapting the image processing algorithms and database parameters to automatically and consistently deliver the preferred rendering, will affect both the technologists' and the radiologists' satisfaction with the capture device.

This course will review fundamentals of image processing for digital radiography. Specific course content will include a discussion of radiographic image segmentation, correlation of image content with different regions of the histogram, and a review of image-rendering functions, including the tone scale, spatial frequency methods to enhance contrast, and signal equalization. The course will also include a review of the role of image processing in the end-to-end image chain (capture through interpretation), with considerations for image quality performance of different capture and display devices, the effect of the human visual system and ambient viewing conditions, and grayscale calibration.

Imaging Continuing Education Course Room 611
CE: Computed Tomography Physics and Technology - III

WE-A-I-611-01
Cone Beam 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) for a 2D parallel beam geometry. 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 6E
CE: QA for IMRT - III

WE-A-T-6E-01
Tools for IMRT QA
N Dogan*, Virginia Commonwealth University, Richmond, VA

The intensity Modulated Radiation therapy (IMRT) is an advanced form of three-dimensional conformal radiation therapy (3-D CRT) that not only uses 3-D imaging and treatment delivery, but allows for varying radiation beam intensities to produce much more conformal dose distributions than those possible with conventional 3-D CRT. The complex nature of IMRT planning and delivery impose new requirements for quality assurance (QA) process. A comprehensive QA for IMRT must address the issues involving the verification of pre-treatment, patient-specific, delivery and post-treatment.

A complete set of tools, including detectors and phantoms, and techniques are necessary to accomplish the new QA tasks. Some of the detectors used for IMRT QA include films, TLDs, EPIDs, ion chambers and gel dosimeters. Each of them has distinct characteristics and limitations. Several phantoms are also available to accomplish the verification measurements, including cylindrical or a stack of solid water. Tools also have been developed for the dosimetric analysis of the measurements and calculations. Some of these tools include isodose overlay, dose difference histograms, distance-to-agreement and gamma evaluation. This presentation will review the QA tools and techniques that are currently in use for all aspects of IMRT process.

Educational Objectives:
1. To identify the QA tasks involving IMRT
2. To identify the requirements for the QA tools
3. To describe the QA tools for all aspects of IMRT process
4. To explain the limitations of the QA tools
5. To compare the IMRT QA tools and techniques

Therapy Continuing Education Course Room 6C
CE: HDR for Breast

WE-A-T-6C-01
The Physics of HDR Breast Brachytherapy
B Thomadsen*, R Das, R Patel, University of Wisconsin, Madison, WI, University of Wisconsin - Madison, Madison, WI

Purpose: To discuss physical considerations of breast brachytherapy. **Method and Materials:** Breast brachytherapy is rapidly becoming a common procedure, driven, to a great extent, by patient demand. Most therapy regimens deliver the definitive course over four or five days of B.I.D. treatments. The treatments irradiate the target at risk without unnecessary exposure to skin (except as noted below) or lung. The placement of catheters is performed with a minimum of pain, and the patients tolerate well the presence of catheters over the week duration. Currently, there are two approaches to breast brachytherapy. One major approach places the patient prone on a breast biopsy table with the target breast hanging through a hole in the table. Using a digital mammography unit, the radiation oncologist places a needle-guiding template on the breast. Holes in the template are selected that cover the tylecomy cavity plus a 2 cm margin (the clinical target volume, CTV). Another approach begins with the patient supine, and uses either ultrasound or CT guidance for needle placement. With any of the approaches, flexible catheters replace the needles, and CT images are taken for dosimetry planning. Optimization molds the prescription isodose surface to the CTV, with no coalescing of the 150 percent isodose surface around more than single catheters.

The other approach uses a single balloon catheter placed in the tylectomy cavity, either at the time of surgery or shortly thereafter. While easier for both the patient and the physician, placing the catheter at the time of surgery runs the risk of having to remove it if pathological examination shows insufficient margins around the tumor. The balloon is then filled with saline and dilute contrast medium to fill the cavity. The dose is prescribed to an isodose surface 1 cm beyond the balloon surface. For spherical balloons, often a single dwell position is placed in the center of the balloon, although some facilities add short dwells along the catheter to compensate for source anisotropy. Oblong balloons always require multiple dwell positions. The intracavitary approach often produces higher skin doses than the interstitial, and finding a skin dose greater than 150% is reason to abort the treatment. Air cavities often become trapped near the surface of the balloon, pushing the target tissue outside the treatment levels of dose. While the air pockets sometimes disappear with time, they often simply fill with fluid, leaving the target tissue at a great distance. Only MRI can determine if the tissue has collapsed onto the balloon or the pocket filled with fluid. Air pockets of 1 mm and 1.6 mm reduce the dose to target tissue by 5% and 10% respectively.

For either approach, quality management plays an important role, and prevents inappropriate treatments.

Results: Comparing the two, the intracavitary approach is slightly simpler but more prone to aborting the procedure, while the interstitial approach allows high conformance of the isodose distribution to the CTV. **Conclusion:** Breast brachytherapy provides an effect delivery vehicle for patient breast radiotherapy.

Therapy Continuing Education Course Room 6B
CE: NCI Funding Opportunities

WE-A-T-6B-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.

Imaging Continuing Education Course Room 618
CE: Radiographic and Fluoroscopy Physics and Technology - III

WE-B-I-618-01
Testing Flat Panel Imaging Systems-What the Medical Physicist Needs to Know
J Tomlinson*, Medical Physics Consultants, Ann Arbor, MI

For many years Medical Physicists have evaluated image quality performance on all medical imaging modalities, except radiographic systems. We have looked at resolution and contrast on MRI, CT, fluoroscopic systems, ultrasound systems, and nuclear medicine cameras; but rarely radiographic equipment, especially those having screen-film receptors.

With the increased presence of flat panel digital radiographic systems, which have dedicated detectors as an integral component, it is appropriate for the Medical Physicist to include an analysis of detail and contrast sensitivity as part of acceptance and routine annual testing.

Some vendors provide automated QA hardware and software tools, but these may not give standard results for adequate monitoring. Using commonly available test tools, resolution and contrast sensitivity can be evaluated on each system. Patient radiation dosimetry can also be evaluated for manual and automatic techniques.

Test methods and typical results will be presented, which should help the clinical Medical Physicist to monitor and maintain good image quality performance.

Educational Objectives:
1. The participant will learn simple test methods to evaluate image quality performance on flat panel detectors.
2. Typical and expected results will be presented to provide the participant with thresholds of acceptance.

WE-B-I-618-02
Digital Image Displays – Resolution, Brightness, and Grayscale Calibration
M Flynn*, Henry Ford Health System, Detroit, MI

Digital radiographs from CR, DR, RF, and XA systems are displayed on monitors when the exam is performed, when a radiologist interprets the examination, and when the referring physician or surgeon review the image. The various monitors used typically vary in image quality. Display resolution is influenced by pixel size and viewing distance. Displayed field of view varies with the monitor array size and image zoom. Image brightness influences low contrast detection, peripheral vision, and may effect observer fatigue. The display grayscale influence contrast and may alter the appearance for different viewers unless matched on all monitors. The requirements for resolution, brightness, and grayscale are considered for various situations including RF and XA exam room displays, technologist QC stations, radiologists reading stations, general clinic review stations, surgical display, and conference case presentation.

Educational Objectives:
1. Understand how pixel size and viewing distance influence resolution in relation to visual limits of the human eye.
2. Understand how image brightness influences observer performance.
3. Learn how the grayscale characteristics of clinical display systems can be calibrated to match diagnostic systems.
4. Learn the performance characteristics of displays now available for various applications.

Imaging Continuing Education Course Room 617
CE: Magnetic Resonance Imaging Physics and Technology - III

WE-B-I-617-01
Optimizing MRI Protocols - Clinical Practice and Compromises
G Clarke*, UT Health Sciences Center, San Antonio, TX

Modern MRI systems are extremely flexible so that optimal usage requires a solid understanding of the physics of the basic processes involved. In the end, determination of the "best" protocol to address a clinical problem requires careful consideration of trade-offs between image contrast, signal-to-noise ratio (SNR), spatial resolution, temporal resolution and patient safety. The major factors in considering MR image contrast are the relaxation times: T1 & T2, magnetization transfer mechanisms, physiological motion and the radio frequency (rf) pulsing scheme. The most important issues for SNR are field strength, rf coil properties, voxel size, and receiver bandwidth. Factors pertinent to spatial resolution include magnetic field homogeneity, gradient strength, matrix size, slice thickness and field of view. Imaging speed is determined by gradient slew rate, signal digitization rate, number of slices, parallel imaging mode & signal-to-noise ratio. Patient safety issues are related to patient size, field strength, rf pulsing method and gradient slew rate.

In this presentation the basic relationships amongst all of these parameters in MRI will be reviewed and their interactions discussed. For instance, the long TR values required for strongly T2-weighted images is an example of how contrast requirements can limit imaging speed. High-speed T2-weighted images can be obtained using Fast Spin Echo strategies, but only by compromising spatial resolution and the number of slices while increasing rf heating.

Specialized clinical imaging protocols that push the envelope in several of these general areas will also be examined. The use of three-dimensional MR angiography to maximize contrast while preserving good SNR at high imaging speeds will be explored. The conditions under which certain signals from particular types of tissues, such as adipose or cerebrospinal fluid, can be entirely eliminated will be surveyed. Roles for the use of exogenous agents to alter tissue contrast shall also be reviewed. Trade-offs required to image the heart's motion in real time will be appraised. The implications of rf heating, as measured by the specific absorption rate, will also be considered.

At the end of this presentation the attendee shall:
1. understand the primary types of image contrast used in clinical MRI and the relationships between pulse timing parameters and relaxation times of tissue on the acquired MRI signal.
2. know how to consider the interactions between SNR, spatial resolution and imaging speed and their relative weighting in defining image quality for a variety of clinical situations.
3. be conversant with circumstances under which patient physiology and magnet field strength may require modification of image acquisition parameters to achieve optimal image quality.

Imaging Continuing Education Course Room 609
CE: Ultrasound Imaging Physics and Technology - III

WE-B-I-609-01

The Ultrasound Research Interface: A New Tool for Biomedical Investigations

J Zagzebski*[1], S Brunke[2], L Pelissier*[3], T Hall[1], T Wilson[4], (1) Univ of WI Radiation Calibration, Madison, WI, (2) Siemens Medical Systems, Issaquah, WA, (3) Ultrasonix Medical Corporation, Vancouver, BC, CA, (4) Univ Tennessee, Memphis, TN

Digitally controlled ultrasound scanners offer extensive levels of programmability, which enable manufacturers to explore and to readily incorporate alternative beam formation, signal and image processing, networking, and interfacing capabilities. Recent efforts have led manufacturers to share these tools for innovation with academic and clinical researchers. This discussion will present capabilities of two such machines and present examples of research uses.

The Axius Direct Ultrasound Research Interface (URI) available on the Siemens SONOLINE Antares™ scanner enables users to acquire raw radio frequency data from regions of interest throughout the image plane. Echo data are available in B-mode, M-mode, pulse Doppler and color flow imaging modes. Data can be acquired to a file with a simple button press.Also, user defined scripts can be used to record and reproduce RF acquisitions for combinations of front panel control settings such as transmit level, center frequency, beam angle, and focal depth. The NIH supported development of the interface is complemented by a set of Matlab tools developed at the University of California at Davis, which read echo and image data and perform image processing operations.

The Sonix RP research system from Ultrasonix is based on an open PC platform, in which the conventional exam software can run either as a single application or as one of separate windows on the display. The PC also runs connectivity, interface and control software in parallel. The computer can control imaging parameters and apply various post-processing and display methods in real-time on RF, I/Q and envelope data to output and store the ultrasound information. When in research mode, users can build, develop, and run client software applications in the Microsoft Visual Studio environment to do customized signal processing, carry out special echo acquisition sequences, and synchronize with external devices, such as stepper motors. These tasks can be accomplished either locally or over a network.

Examples of the use of these systems that will be outlined include parametric ultrasound imaging, elasticity imaging, and measuring the speed of sound in pulse-echo mode.

Imaging Continuing Education Course Room 611
CE: Radiation Safety and Risk Management – III

WE-B-I-611-01

Evaluation and Consulting On Patient Dose In Diagnostic Imaging

J Gray*[1], J Kofler[2], (1) Landauer, Inc., Glenwood, IL, (2) Mayo Clinic, Rochester, MN

One of the responsibilities of a clinical medical physicist in diagnostic imaging is to provide both dose and risk information about x-ray examinations. This is required for several reasons including advising medical staff of the doses and risks associated with specific examinations, consulting with institutional review boards (IRBs) relative to research uses of radiation, and determining specific organ doses such as uterine or fetal doses to assist in medical decision making.

In order to provide dose and risk estimates four types of information are necessary including: 1) patient entrance skin exposures; 2) specific organ doses based on these exposures; 3) effective dose which is calculated based upon specific organ doses; and 4) estimation of risk based upon the effective dose. Unfortunately, there is no concise source of the information regarding doses and risk so it is necessary to have access to and knowledge of the sources that are available. This refresher course will provide an overview of resources and methods for determining patient risk from ionizing radiation in medical imaging. Several examples will be provided showing how doses and risks can be reduced easily and inexpensively for both clinical and research applications.

Therapy Continuing Education Course Room 6E
CE: Monte Carlo for Radiotherapy - I

WE-B-T-6E-01

Source Modelling and Beam Commissioning for Monte Carlo Treatment Planning

C Ma*[1], B Faddegon*[2], B Curran*[3], (1) Fox Chase Cancer Center, Philadelphia, PA, (2) UC San Francisco, San Francisco, CA, (3) Univ Michigan Medical Center, Ann Arbor, MI

Source modeling and beam commissioning are important components of a Monte Carlo based treatment planning system. In this presentation, 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. We will discuss problems associated with CT scanning and phantoms that can affect Monte Carlo accuracy. We will describe requirements and procedures for commissioning and acceptance testing of Monte Carlo dose calculation software for radiotherapy treatment planning.

Educational Objectives:

1. Introduce 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
5. Provide requirements and guidelines for the clinical testing of Monte Carlo dose calculation software for radiotherapy treatment planning

Therapy Continuing Education Course Room 6C
CE: Imaging for Treatment Planning - III

WE-B-T-6C-01

Positron Emission Tomography for Oncologic Imaging and Treatment

JD Bourland*, Wake Forest Univ, Winston Salem, NC

Purpose: Positron Emission Tomography (PET) provides images that show physiological and biological information through the distribution of a radioactive tracer material. Imaging of oncology patients using PET can demonstrate focal and distributed regions of cancer and its metastases. Uses of PET imaging include cancer diagnosis and especially cancer staging, such that prognosis and appropriate treatment can be rendered. **Method and Materials:** Fluorine-18-labled Fluoro-deoxyglucose (F-18 FDG) is the most commonly used radiolabeled agent for PET imaging. Though non-specific in its deposition, FDG labels those regions with active glucose metabolism, such as for local cancer, metastasis, and for non-cancer processes such as glucose use by the brain. Non-FDG positron-emitting agents that are highly specific in their tissue targeting can also be used, such as Fluorine-18 Misonidazole (F-MISO) and Carbon-11 Methionine, to image biological processes that are important indicators of tumor biology, for instance, hypoxia (F-MISO) and cell proliferation (Methionine). **Results:** PET images have relatively coarse spatial resolution compared to computed tomography and magnetic resonance images. Voxel intensity (signal strength) depends on patient and imaging study parameters – quantitative use is possible with limitations. **Conclusion:** This course reviews the basic physics of PET, the uses of FDG and non-FDG PET for oncology patient imaging, and logistical and quantitative aspects for uses of PET images in the radiation treatment process. Work by others and the

author demonstrates the potential contributions of FDG and non-FDG PET imaging in the radiation oncology environment. This review course is intended for both imaging and radiation oncology physicists. **Conflict of Interest:** The author has research grants with Varian Medical Systems and General Electric Healthcare.

Therapy Continuing Education Course Room 6B
CE: Planning and Delivery - Pediatric Radiotherapy

WE-B-T-6B-01
Planning and Delivery- Pediatric Radiotherapy
A Olch*, 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 609
Image Processing and CAD

WE-C-I-609-01
Computer-Aided Diagnosis: Computerized Classification of Malignant and Benign Microcalcifications On Full Field Digital Mammograms
H-P Chan*, L Hadjiiski, J Ge, B Sahiner, M Helvie, Univ Michigan, Ann Arbor, MI, University of Michigan, Ann Arbor, MI

Purpose: To develop a computer-aided diagnosis (CAD) system for characterization of malignant and benign microcalcifications on mammograms acquired with a full field digital mammography (FFDM) system. **Method and Materials:** Our computerized classification system uses raw digital mammograms as input. The individual microcalcifications are first segmented by the system from the mammographic breast tissue background. Five morphological features describing the size, the density, and the shape of the individual microcalcifications are extracted. The mean and the variation of each of these features for the individual microcalcifications within a cluster are calculated. These cluster features in combination with the number of microcalcifications in a cluster form the morphological feature space. For texture feature extraction, a region of interest (ROI) containing the cluster of microcalcifications is identified on the mammogram. Background correction is applied to the ROI to reduce the intensity variation in the breast tissue areas. Texture features including the mean, entropy, contrast, and angular second moment are extracted from the gray level dependence difference statistics of the background-corrected ROIs in four directions. A leave-one-case-out resampling scheme is used to train and test the linear discriminant classifier. The most effective features from the combined morphological and texture feature space are identified using stepwise feature selection with simplex optimization in each training cycle. The performance of the classifier is evaluated by receiver operating characteristic (ROC) analysis. **Results:** In a preliminary study using digitized mammograms, the computer classifier obtained an area under the ROC curve, A_z, of 0.82 ± 0.03 for testing. The performance of the CAD system using a data set of 100 cases of biopsy-proven microcalcifications on FFDMs will be presented. **Conclusion:** A trained CAD system can provide an estimate of the likelihood of malignancy of microcalcification on mammograms and thus may be used as a second opinion by radiologists for mammographic interpretation.

WE-C-I-609-02
Investigation of Various Methods for Determination of Similarity Measures for Pairs of Clustered Microcalcifications On Mammograms
C Muramatsu*, Q Li, RA Schmidt, K Suzuki, J Shiraishi, GM Newstead, K Doi, The University of Chicago, Chicago, IL

Purpose: Presentation of images similar to an unknown lesion on mammograms may be useful to radiologists in their image interpretation. The purpose of this study is to investigate different methods for determination of similarity measures that would agree with radiologists' subjective similarity ratings. **Method and Materials:** We used 881 ROIs that included clustered microcalcifications. We selected 19 "unknown" images each of which was compared with six "known" images to produce 114 pairs. Nine breast radiologists provided similarity ratings based on the overall impression for diagnosis for the 114 pairs. Subjective ratings were marked on a continuous rating scale between 0 and 1, where 0 and 1 correspond to two lesions not similar at all and almost identical, respectively. A number of image features were extracted from the lesions for determination of similarity measures. Two similarity measures were determined by use of the Euclidean distance without and with unique strong features of an unknown image. A psychophysical similarity measure was determined by use of an ANN that can learn the relationship between radiologists' similarity ratings and feature values. The correlation values between the subjective ratings and the similarity measures were determined to evaluate the usefulness of similarity measures. **Results:** The Euclidean-distance-based measure with unique features provided the improved correlation values for four cases, but degraded correlation values for three cases, compared with that without unique features. When ANN was employed, the correlation coefficients were further improved by use of a leave-one-out test method. **Conclusion:** Simple similarity measures such as those based on the Euclidean distance would not be a reliable measure. The selection of features for a specific unknown case and the use of ANN have the potential to improve the determination of reliable similarity measures. **Conflict of Interest:** RAS and KD: shareholders, R2 Technology Inc.; KD: shareholder, Deus Technology Inc.

WE-C-I-609-03

Study of Radial Gradient Features in LDA Classifier for Automated CT Lung Nodule Detection

A Roy*, S Armato, The University of Chicago, Chicago, IL, Chicago, IL

Purpose: To study the use of radial gradient index features by an LDA classifier for false positive reduction in automated CT lung nodule detection. **Method and Materials:** Our database contains 38 diagnostic CT scans, with a total of 82 lung nodules. A radial gradient index (RGI)-based approach is used to reduce false positives detected by our automated method. For each CT section a complementary image (an "RGI map") is generated in which the pixel intensity is proportional to the RGI computed along a circle of chosen diameter d, centered at that pixel. As the RGI is maximum for a perfect circle, an RGI map enhances the intensity of nodules relative to neighboring anatomic structures. For every candidate we calculate a set of three RGI features, for each of five different values of the RGI diameter. We evaluate the performance of the classifier by introducing in turn RGI features corresponding to a particular diameter, together with an optimal set of 9 non-RGI features determined previously. The results are compared with the performance of the LDA without RGI features. Finally, we use stepwise LDA in order to identify optimal features. **Results:** The performance for d = [12, 16, 20] is optimal (the sensitivity increases from 70 % to 79 % at 0.5 false detections/section) while for $d \geq 24$ performance decreases. A stepwise LDA was performed for 10 random partitions of the database in order to evaluate the relative weight of different features for classification. This revealed that 8 out of 15 RGI features were included 9 or more times within the optimal feature set. **Conclusion:** Inclusion of RGI features results in a substantially improved FROC performance, which is consistent with results of stepwise linear discriminant analysis. **Conflict of Interest:** SGA is a shareholder in R2 Technology, Inc.

WE-C-I-609-04

Observer Evaluation of Semi-Automated Mesothelioma Measurements

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Purpose: Accurate quantification of malignant pleural mesothelioma tumor burden is essential for proper patient management and for the conduct of clinical trials. Although manual measurement of tumor thickness on computed tomography (CT) scans is the current clinical standard for assessing response to therapy, this approach is tedious and time-consuming. We have developed semi-automated methods to quantify the extent of mesothelioma on CT scans, and we have assessed the performance of these methods through an observer evaluation study. **Method and Materials:** Given a user-specified point along the outer margin of the tumor in a CT section, the computer automatically identifies a corresponding point along the inner margin of the tumor and displays a line segment between the user-specified outer tumor margin point and the computer-identified inner tumor margin point. The length of this line segment represents tumor thickness. Three observers independently reviewed semi-automated measurements (i.e., line segments and their corresponding lengths) generated by three different algorithms at a fixed set of 134 measurement sites in the CT scans of 22 mesothelioma patients. These algorithms are based on morphological characteristics of the automatically segmented lung regions. Observers had the opportunity to accept a measurement or to modify it through a computer interface. Differences between the initial semi-automated measurements and the measurements as modified by the observers were analyzed. **Results:** The frequency with which observers accepted the semi-automated measurements without modification was as high as 86%. Of all measurements across all observers and methods (1206 measurements), 89% were changed by less than 2 mm. **Conclusion:** We expect these promising computerized methods to become important components of clinical protocols for mesothelioma by making the quantification of tumor extent more efficient and consistent. **Conflict of Interest:** SGA and HM hold warrants to shares of R2 Technology, Inc. (Sunnyvale, CA).

WE-C-I-609-05

Temporal Radiographic Texture Analysis for the Detection of Periprosthetic Osteolysis

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Purpose: We have been investigating temporal radiographic texture analysis (RTA) as a method to help detect the disease periprosthetic osteolysis associated with total hip arthroplasties. This disease is a common but difficult to detect long-term complication for total hip replacement patients. It typically goes unnoticed on radiographs until at least seven years after the operation. The goal of our research is to assess the ability of temporal RTA to detect osteolysis before it is visible radiographically. **Method and Materials:** We obtained digitized pelvis radiographs from 84 total hip replacement cases from the Anderson Orthopaedic Research Institute. Each case included a baseline image taken shortly after surgery and follow-up images taken at various time intervals. The cases were assessed for osteolysis by an orthopaedic surgeon and regions of interest (ROIs) were selected within the osteolytic region (or a comparable region for normal cases) on the final image of each case. These ROIs were then visually matched on all previous images. Fourier-based, fractal-based and correlation-based features were calculated for each ROI. To measure temporal trends in feature values, we calculated the slope of the least squares fitted line for each case using data through five year and nine year time ranges, respectively. Temporal feature performance was examined using Receiver Operating Characteristic (ROC) analysis. **Results:** Forty-four cases were determined to have osteolysis while forty were normal. A_z values from ROC curves ranged from 0.6 to 0.75 for the task of distinguishing between osteolysis and normal cases for both time ranges. **Conclusion:** Temporal RTA appears to have the potential to help detect periprosthetic osteolysis before visual radiographic appearance of the disease. More development of temporal RTA and analysis with a larger patient database is therefore warranted. **Conflict of Interest:** M.L.G. is a shareholder in R2 Technology, Inc. (Sunnyvale, CA).

WE-C-I-609-06

Computerized Texture Analysis of Abnormal Areae Gastricae On Double-Contrast Barium Examinations

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Purpose: Abnormal areae gastricae occur in the body due to gastritis. Very frequently, gastritis is caused by the Heliobactor Pylori bacteria, in which case it can be treated with antibiotics. The purpose of this study is to assess the ability of computerized radiographic texture analysis to recognize the presence of abnormal areae gastricae. Potentially, this could aid radiologists in classifying radiographic features of the areae gastricae in pathologic states. **Method and Materials:** Digitized double-contrast radiographs for 23 cases were obtained. Each case was classified as normal or abnormal based on clinical symptoms and the results of endoscopic examination, H Pylori testing, and/or barium examination. Similar locations of the gastric area were selected on each image from the lower region of the stomach. These regions were then divided into 64 x 64 and 128 x 128 regions of interest (ROI) for texture analysis. Standard deviation, and Fourier and Fractal based features were calculated for all ROIs. ROC analysis was performed on the results to test the ability to distinguish between normal and gastritic cases, using round-robin analysis. **Results:** The texture analysis showed that there is a separation between the normal and abnormal cases. For 64 x 64 ROIs, ROC analysis yielded Az values in a range of 0.54 to 0.80 for single features and a range of 0.70 to 0.806 for multiple features. For 128 x 128 ROIs, single feature ROC analysis yielded Az values in a range of 0.55 to 0.85 for single features and a range of 0.77 to 0.8694 for multiple features. **Conclusion:** The results indicate that radiographic texture analysis of digitized double-contrast radiographs have the potential to distinguish between normal and abnormal cases of areae gastricae. **Conflict of Interest:** ML Giger is a shareholder in R2 Technology, Inc., Sunnyvale, CA.

WE-C-I-609-07

On Constructing Priors and Likelihoods for Deformable Shape Models

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Purpose: Explicit deformable shape models (DSMs) can be used in a Bayesian statistical framework to provide *a priori* information for posterior optimization to match the DSM against a target image for automatic segmentation. In this approach a DSM is initialized in the target image and undergoes a series of deformations to closely match the target object. Deformation is driven by optimizing an objective function with terms for geometric typicality (prior) and model-to-image match (likelihood). The purpose of this work was to develop strategy, methodology, and tools for constructing the geometric prior and intensity likelihood for a particular form of DSM called m-reps. **Method and Materials:** Geometric truth is defined for an object of interest by a statistically significant collection of expert human segmentations of training images. M-reps are fit to the human drawn contours by minimizing the distance between the surfaces of the m-rep and the contours under added conditions that lead to positional correspondence across training cases. The geometry of the resulting set of training m-reps is analyzed in non-Euclidean space using an approach called principal geodesic analysis (PGA) to yield a set of eigenmodes that define the geometric prior. The intensity likelihood is constructed by registering each training m-rep with the corresponding gray scale image and collecting regional intensity information that is statistically characterized over all training cases. The intensity information can be in several forms including linear profiles and regional histograms. **Results:** PGA produces modes that include natural deformations such as local twisting, bending, bulging, and constricting. Unlike analysis in Euclidean space, improper shapes are avoided. The form of the intensity prior can be customized to each object of interest for optimal performance. **Conclusion:** These methods are powerful, robust and generalizable to other DSMs. **Conflict of Interest:** The presenting author has a financial interest in Morphormics, Inc.

WE-C-I-609-08

Information Theoretic Contours for Radiotherapy Planning

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Purpose: To develop contouring tools that aid in the work of anatomy delineation in CT imagery. Our strategy is to estimate the organ boundary on a CT image using that image's properties and the shape and pixel textures associated with the contour already computed on an adjacent section. **Method and Materials:** CT image regions can be effectively segmented using information divergences, which expand or shrink a boundary to maximize the differences between the pixel-sets inside and outside the boundary. Divergences produce non-parametric, statistical inferences generating minimum average error contours, given the data. We constructed an objective function using divergence functions that 1) maximize the match of regions and edges in multiple images, and 2) constrain the flexible contour to minimize differences between the current image and the prior image's region pixel textures and contour shapes. The resulting contour is the result of literally all the information in both the current and prior images. The novel features of this project are the pixel texture constraint using minimum divergences, an objective function whose term weights may be varied to optimally contour regions in various anatomies in CT, including envelopes of organs that are unresolvable because of patient motion. **Results:** The information divergence objective function computes series of contours without user input, beginning from an initial section. The contours can describe discrete natomic organs, or regions containing the envelope of an organ in which some of the anatomy is distorted or obscured by patient motion. The computed contours adapt well to changes in size and shape. **Conclusion:** Nonparametric information theoretic divergences don't require a model (e.g., Gaussian) to make effective estimates of anatomic boundaries in CT images. Their application to RT planning could greatly increase the efficiency of plan preparation.

WE-C-I-609-09

Autostereoscopic Display of the 3D Dose Distribution to Assess Beam Placement for Robotic Radiosurgery

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Purpose: To study whether a 3D view of the dose distribution and treatment beams on an autostereoscopic display facilitates a 'smart' placement of additional beams for robotic radiosurgery. **Method and Materials:** Treatment plans for robotic radiosurgery with the CyberKnife system (Accuray Inc., Sunnyvale) consist of a large number of non-isocentrical, cylindrical beams directed towards arbitrary points within the target volume. We implemented a tool to visualize the resulting 3D dose distribution and the beam directions using the visualization toolkit (VTK). A hypsometric color scheme allows to identify cold and hot spots in the target volume, i.e. regions where the dose is close to the lower or upper bound specified for the target. Given this information we manually added a 20 beams to an existing treatment plan with 1200 beams for an intracranial tumor. The beams where placed such that a large number of cold voxels were hit but hot voxels were avoided. To assess the spatial extent of the cold and hot regions and the orientation of the beams an autostereoscopic display (SeeReal Technologies GmbH, Dresden) was used. An inverse planning algorithm similar to the one used by the CyberKnife system was implemented to re-optimize the plan, the result was compared to the original plan. **Results:** The original plan consisted of 119 weighted beams with an accumulated weight of 21763.3 MU. Adding 20 beams we obtained a plan with 123 beams with the total weight reduced to 21610.7 MU. All 20 new beams got the maximum weight of 250 MU per beam, i.e. other, less efficient beams were discarded by the optimizer. **Conclusion:** The visualization tool proved to be useful in the guidance of beam placement. A direction of additional beams towards cold spots in the target volume can improve the plan quality.

WE-C-I-609-10

A Feasibility Study of Atlas-Based Image Segmentation in 3D Treatment Planning

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Purpose: To develop and evaluate a fully automatic atlas-based image segmentation method for radiotherapy treatment planning. **Method and Materials:** A very important part of 3-dimensional radiotherapy treatment planning is the contouring of normal regions of interests (ROIs). Currently, automatic image segmentation tools provided in treatment planning systems are usually based on edge detection and may not always be satisfactory. Atlas-based image segmentation is a promising method that uses deformable image registration to register the target images with reference images containing previously contoured ROIs. Atlas-based image segmentation utilizes all of the information in the images and has the potential to perform better than edge-detection based algorithms, in which only the edge information is used.

The performance of atlas-based image segmentation relies on the deformable image registration algorithm. We implemented a fast variational deformable image registration algorithm. The algorithm was tested at three common radiotherapy sites: head/neck, chest and pelvis. Physicians manually contoured the ROIs in the reference CT images. The new, randomly selected target images were automatically contoured. The results were evaluated by the physicians. **Results:** The entire process was completed in less than 15 minutes using a single CPU computer. The ROI masks were transformed into the new images using the displacement maps from deformable image registration. Contours were regenerated from the ROI masks and imported into the Pinnacle™ treatment planning system. In all three clinical sites, the majority of generated ROI's required only minor further modifications. **Conclusions:** Atlas-based image segmentation is a powerful automatic contouring tool. Our algorithm provides excellent results in a majority of clinical cases. Implementation of atlas-based image segmentation may reduce the time required by physicians to contour normal structure ROI's in treatment planning. Additionally, it opens up the possibility of standardizing ROI contours, such as the parotid, in head and neck IMRT.

Imaging Symposium — Room 611

X-ray Fluoroscopy and Angiography: The State of the Art

WE-C-I-611-01

Basic System Design and Application

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The use of real-time or rapid sequence x-ray imaging has been increasing. Not only are the GI and cardiology applications to diagnostic procedures of continuing interest, but new image guided interventional procedures are being developed which rely on the combination of high spatial and temporal resolution x-ray imaging. In particular, rotational angiographic sequences combined with cone-beam computed tomography have enabled advances in minimally invasive endovascular interventional procedures to often replace invasive surgical procedures. In this symposium, after a review of some of the clinical applications of dynamic x-ray imaging including fluoroscopy and angiography, we will discuss some of the unique problems associated with image quality evaluation for such total x-ray imaging systems, as well as review some of the new developments in detector design with a comparison of flat panel and image intensifier-based systems. Also we will discuss developments in cone-beam computed tomography with specific application to angiography and ultimately to the potential for changing the treatment paradigm for vascular disease through the combination of computerized blood flow analysis and angiographic image guided interventions.

Educational Objectives
1. To appreciate the widening clinical application of dynamic x-ray imaging to diagnostic and interventions.
2. To indicate the quality evaluation issues in total x-ray imaging systems as well as the new developments of digital detectors and cone-beam computed tomography.

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WE-C-I-611-02

Composite Fluorographic System Evaluation

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This presentation explores methods for the assessment of total fluorographic system performance as related to typical clinical tasks. Many quantitative imaging system analyses focus on separately evaluating the characteristics of the individual system components. Although there is a place for such individualized characterization in product specification and troubleshooting, image quality depends on the interaction of a number of factors including the focal spot characteristics, the projection geometry of the object of interest, scattered radiation, and the image receptor. To determine how the system will perform requires a composite evaluation that includes the net effect of all components impacting image quality under clinical conditions. This is the intent of the NEMA XR 21-2000 Standard that specifies a procedure and phantom "to benchmark cardiac fluoroscopic and fluorographic performance." This standard provides a qualitative method of evaluation that is dependent on "trained human observers." For a quantitative analysis, a generalized systems approach has been developed to determine the GMTF, GNNPS, GNEQ and GDQE. This presentation reviews the mechanics of these methods and explores the advantages as well as limitations of composite system evaluation as opposed to component evaluation.

Educational Objectives**:**
1. To provide an understanding of those factors that influence the image quality of fluorographic systems
2. To describe methods of total system performance evaluation
3. To explore the usefulness and limitations of the NEMA XR 21 standard
4. To review the steps in the determination of the generalized system parameters of GMTF, GNNPS, GNEQ, and GDQE.

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WE-C-I-611-03

Flat Panels Vs. IIs: A Critical Comparison

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Over the past decade there has been rapid development of real-time active matrix flat-panel imagers (AMFPI) to replace the x-ray image intensifiers (XRII) in fluoroscopy and angiography. The major advantages of AMFPI compared to the conventional XRII are: (1) compact and light weight; (2) free of distortion; (3) use of lower-z material for detector window, which increases the quantum absorption efficiency of the detector; (4) free of veiling glare. Depending on the materials used for x-ray detection, AMFPI are divided into two main categories: *direct* and *indirect* detection. Direct detection AMFPI employ a uniform layer of x-ray sensitive photoconductor, e.g., amorphous selenium (a-Se) to directly convert incident x-rays to charge, which is subsequently read out by a two dimensional array of amorphous silicon (a-Si) thin film transistors (TFTs). In indirect AMFPI, a phosphor such as structured cesium iodide (CsI) is used to convert x-ray energy to optical photons, which are then converted to charge by integrated photodiodes at each pixel of the TFT array. The principle of operation, and advantages and disadvantages of both direct and indirect AMFPI will be described. The imaging performance of both approaches, and their comparison with the XRII will be presented. The evaluation of imaging performance includes: (1) the spatial frequency (*f*) dependent detective quantum efficiency (DQE); (2) DQE(*f*) as a function of x-ray exposure; (3) temporal performance, i.e. lag and image persistence; and (4) veiling glare. Despite their differences in detector structure, the direct and indirect AMFPI have comparable imaging performance. The DQE(*f*) of AMFPI compares favorably to XRII except at the lowest exposure encountered in fluoroscopy (< 5 nGy), where the electronic noise of AMFPI degrades the DQE. To improve the DQE at low dose is the focus of many recent developments of both direct and indirect AMFPI. For direct AMFPI, photoconductors of higher z and x-ray to charge conversion gain, e.g. lead iodide (PbI_2) and mercuric iodide (HgI_2), have been developed. The x-ray to charge conversion gain for these new photoconductors is seven times higher than that of a-Se. For indirect AMFPI, a thin layer of a-Se avalanche photoconductor is being investigated as a replacement for a-Si photodiodes. Under electric field of > 80 V per micron, avalanche multiplication occurs in a-Se, which can amplify the signal in low dose applications. Sophisticated pixel structures (by incorporating more than three TFTs at each pixel) are also being proposed, which provide signal amplification at each pixel to reduce the electronic noise. This approach can be applied to both the direct and indirect AMFPI. The principle of operation, feasibility and advantages of each new AMFPI concept will be discussed.

Educational Objectives:
1. To understand the principle of operation and imaging performance of different AMFPI, and their advantages and disadvantages compared to XRII.
2. To understand the limitation of existing AMFPI in low dose performance, and learn about the current development and advancement in AMFPI design to overcome this limitation.

WE-C-I-611-04

New Developments

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In recent years, the norm for new angiography gantries has become the ability to rotate the x-ray source and detector assembly around the patient so as to obtain enough projection views and enable a complete computer back-projection calculation to be made followed by a display of 3D vascular trees. This cone-beam computed tomography where multiple cross-sectional planes of the patient are taken simultaneously has enabled quicker and better diagnoses as well as more accurate selection of views during subsequent treatment. Most recently, it has become apparent that extreme accuracy may only be necessary at the site of an intervention and hence that truncated or region-of-interest cone-beam CT, rather than full field CT, is required. The use of high spatial resolution detectors over a small region of interest near the site of an intervention, usually near the catheter tip, has enabled the possible use of new endovascular devices, such as an asymmetric stent, for treatment of neurovascular aneurysms. The combination of high spatial resolution, 3D determination of vessel lumen, and new patient specific endovascular interventional devices appears to be leading to a new paradigm in the treatment of vascular disease that may influence the way in which the medical physicist relates to such therapies. Just as the therapeutic medical physicist may be involved closely with radiation therapy treatment plans for individual patients, the imaging

physicist may become increasingly involved with the individual intervention for vascular patients. Once a patient's vessel lumen has been determined from high resolution ROI cone-beam CT, the detailed blood flow patterns could be calculated using computer fluid dynamic (CFD) software. A patient-specific endovascular therapeutic device could then be designed, and its potential impact in flow modification, e.g., the closing off of an aneurysm using an asymmetric stent, could be optimized in simulations. Next, the device would be either fabricated or selected from available devices. The patient would then be treated under high-resolution image guidance and evaluation of modified flow made using image analysis and further CFD calculations. The imaging physicist would play a unique role in the design, evaluation, and guidance of future minimally-invasive vascular interventions.

Educational Objectives:
1. To review cone-beam CT based on rotational angiography.
2. To explain the problems associated with truncated CT and how ROI CT may solve these and provide adequate 3D imagery near the site of an intervention.
3. To discuss microangiography detectors and their possible application.
4. To introduce new endovascular interventional devices such as asymmetric stents.
5. To introduce a new treatment paradigm and potential new role for imaging medical physicists involving the combination of image analysis, flow calculations, endovascular device design, and image-guided interventions.

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Joint Imaging/Therapy Scientific Session Room 6C
Image-Guided Radiotherapy Strategies

WE-C-J-6C-01
Residual Motion of Lung Tumors in Gated Radiotherapy with External Respiratory Surrogates

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Purpose: To mitigate the motion-induced irradiation of healthy lung tissue, clinics have begun using external markers to gate the therapy beam. This technique assumes that the correlation between the external signal and the internal tumor position remains constant inter-fractionally and intra-fractionally. A study has been performed to assess the validity of this correlation assumption within a gating window. **Method and Materials:** Eight lung patients with implanted fiducials were studied. Synchronized internal and external data was taken during the entire course of treatment. Stereoscopic imaging was used to find the internal markers in four dimensions. The data was used retrospectively to assess conventional external surrogate respiratory-gated treatment. Both amplitude and phase-based gating methods were investigated. For each method, three gating windows were investigated, each giving 40%, 30% and 20% duty cycle, respectively. The residual motion of the internal marker within these six gating windows was calculated. The beam-to-beam variation and day-to-day variation in the residual motion were calculated for both gating modalities. **Results:** We found that the residual motion (95^{th} percentile) was between 0.9-6.2 mm for a 40% duty cycle window. There is no clear preference for either gating modality. Large fluctuations (>300%) were seen in the residual motion between some beams. Overall, the mean beam-to-beam variation was 37% and 42% for amplitude and phase-based gating, respectively, compared to the previous beam. The day-to-day variation was 29% and 34% for amplitude and phase-based gating, respectively, compared to the previous day. **Conclusion:** Although gating significantly reduced tumor motion, the residual motion behaved unpredictably. Treatment margins that account for motion should be individualized and daily imaging should be performed to ensure that the residual motion is not exceeding the planned motion on a given day. **Conflict of Interest:** This work was sponsored, in part, by a grant from Varian Medical Systems, Inc.

WE-C-J-6C-02
Investigation of Variables Affecting Residual Motion for Respiratory Gated Radiotherapy

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Purpose: Breathing training may help improve respiration motion regularity. This study was conducted to statistically and clinically determine if residual motion was affected by some characteristics of patients. The aims of this study were: 1) To identify significant characteristics affecting respiratory motion for respiratory-gated radiotherapy, 2) To investigate time trends of respiration motion over a period of days (inter-session) and 3) To investigate time trends of respiration motion within the same day (intra-session). **Method and Materials:** 24-lung cancer patients were enrolled in an IRB approved protocol; acquiring 331, 4-minute, respiration motion traces with free breathing, audio-instructions and audio-visual biofeedback for approximately 5-sessions each. The residual motion was quantified by the standard deviation of the displacement within the gating window.
The generalized linear model was used to obtain coefficients for each variable within the model and evaluate the clinical and statistical significance. The statistical significance was determined by a p-value <0.05 while effect sizes of ≥ 0.05cm were considered clinically significant. Effect size is calculated as the product of estimated coefficients with the range of that variable.
This data analysis was applied to: time independent analysis, inter-session analysis and intra-session analysis. **Results:** Disease type and dose-per-fraction were significant for both inhale and exhale-based gating. In addition, for inhale-based gating visual training displacement, breathing type and Karnosky-performance status values were significant for inhale-based gating. The inter-session and intra-session analysis did not show significant time trends for any of the variables considered. **Conclusion:** Certain variables were found to be significant for time independent analysis. The results of the inter-session analysis indicated that the margin component to account for residual motion during gated radiotherapy remained constant throughout the treatment. Also, the patients breathing did not alter over a period of time within a session and they could maintain the reproducibility during a treatment fraction.

WE-C-J-6C-03
A Novel Respiratory Gating Method Based On Automated Analysis of Ultrasonic Diaphragm Motion

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Purpose: Most of the current respiratory gating systems monitor the abdominal wall movement for lung cancer radiotherapy. These systems make the assumption that this motion and that of the lung tumor are correlated. Diaphragm motion is also correlated with lung tumor motion. Research shows there is a phase shift between the abdominal wall and diaphragm motions. Previous studies used fluoroscopy to evaluate diaphragm motion. We developed a method to extract a respiratory gating signal by automatically analyzing ultrasonic diaphragm video. **Method and Materials:** Volunteers were examined in a supine position and their right diaphragms were imaged with B-mode ultrasonography using a standard unit (Siemens Sonaline Prima). The analog video signal was captured with a standard pc video card (RADEON 9600XT, ATI Technologies Inc.) at a rate of 30 frames per second to decompose the video stream into frames. To reduce computation time and complexity, the region encompassing the diaphragm motion was segmented from all frames. The mutual information and correlation coefficient between a selected reference frame and all others were calculated and normalized. Diaphragm motion information was extracted for use as a respiratory gating signal. **Results:** Plots of either the mutual information or correlation coefficient vs time (frame number) are periodic and match the respiratory cycle. The periodicity is independent of the selected reference frame and the shape shows only minor variations. Thus, this method provides a robust signal of respiratory motion that could be used to trigger the radiation beam. **Conclusion:** A novel respiratory gating system is proposed for lung cancer therapy based on ultrasound imaging. The method is noninvasive, nonionizing, and specific, thus has the potential to be a useful respiratory gating system.

WE-C-J-6C-04

Image-Guided Adaptive Therapy for Lung Cancer

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Purpose: Because the GTV for many lung cancer patients decreased during the course of treatment, the margin effectively gets larger as the tumor reduces in size. This work describes the development and assessment of a technique for image-guided adaptive radiation therapy for lung cancer. **Method and Materials:** Megavoltage CT (MVCT) images of the GTV were acquired daily on a helical tomotherapy system. These images were used to position the patient and to measure reduction in GTV volume. A planning study was conducted to determine the amount of lung-sparing that could have been achieved if adaptive therapy were utilized. Treatment plans were created where the target volumes were reduced following measured tumor reduction. **Results:** A total of 158 MVCT imaging sessions have been performed on 7 lung patients. The GTV reduced by 60 to 80% during the course of treatment. The tumor reduction in the first 60 days of treatment can be modeled using the 2nd order polynomial $R = 0.0002t^2 - 0.0219t + 1.0$, where (R) is the percent reduction in GTV and (t) is the elapsed days. Based on these treatment-planning studies, the absolute volume of ipsilateral lung receiving 20 Gy can be reduced between 5 and 25 percent (*17%* mean) by adapting the treatment delivery. The benefits of adaptive are the greatest for tumor volumes ≥ 25 cm^3 and are directly dependent on the GTV reduction during treatment. **Conclusion:** MVCT based image-guidance can be used to position lung cancer patients daily. This has the potential to decrease margins associated with daily setup error. Furthermore, the adaptive therapy technique described in this work can decrease the volume of healthy lung tissue receiving above 20 Gy. **Conflict of Interest:** Research supported by TomoTherapy, Inc.

WE-C-J-6C-05

Image-Guided Process for 4D Lung Stereotactic Body Radiation Therapy

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Purpose: To present the image-guided process used clinically at Princess Margaret Hospital for stereotactic body radiation therapy (SBRT) of small lung lesions. Respiration correlated cone-beam computed tomography (CBCT) was also investigated retrospectively to assess inter-fraction and intra-fraction target motion on the treatment unit. **Method and Materials:** Five patients with inoperable early stage non-small cell lung carcinoma were treated using image-guided SBRT. For each patient, tumor motion was assessed initially using fluoroscopy on a conventional simulator to determine the requirement for abdominal compression to limit tumor excursion. The planning computed tomography (CT) session involved both helical and four-dimensional CT (4DCT) with compression applied as indicated by fluoroscopy. For SBRT, image guidance was achieved using a kV x-ray tube and amorphous silicon flat-panel detector mounted to the gantry drum of a linear accelerator (Elekta Synergy). Respiration correlated CBCT was also investigated, whereby the kV projections acquired for localization are sorted based on an internal surrogate of the respiration cycle. These sorted projections were reconstructed retrospectively to provide volumetric datasets at different phases in the respiratory cycle. **Results:** Respiration correlated CBCT image datasets were generated for one patient undergoing SBRT. For each treatment fraction, the lung lesion demonstrated excursions consistent with the excursion measured by 4DCT at the time of planning. The lesion was within the limits of the PTV as determined by 4DCT. **Conclusion:** We have established an efficient and streamlined image-guided process that is in clinical use for SBRT of small lung lesions. A framework for on-line respiration correlated CBCT acquisition on the treatment unit is being investigated to allow target motion to be assessed for each treatment fraction. **Conflict of Interest:** Princess Margaret Hospital is part of the Elekta Synergy Consortium. The research presented is supported, in part, by Elekta Inc.

WE-C-J-6C-06

Assessing Prostate Volume Changes During Conformal Radiotherapy Using Implanted Fiducial Markers

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Purpose: Evaluate changes in the volume of the prostate gland during radiation therapy using implanted fiducial markers. **Method and Materials:** The study includes 15 patients being treated for prostate cancer with 84Gy in 42 fractions. Prior to treatment, gold fiducial markers are implanted in the apex, base and posterior aspect of the prostate under ultrasound guidance. Daily on-line image-guidance is achieved using an orthogonal pair of MV portal images. Under research protocol, daily volumetric images are captured using a kV cone-beam CT enabled linac. These images, reconstructed on a fine voxel grid ($0.25mm^3$), allow precise 3-D localization of the implanted markers using a threshold based auto-segmentation technique. Acquisitions that exhibited marker movement due to patient motion were excluded from the analysis. The contoured prostate volumes were between 31.9 and 77.2 cc with a median value of 41.8cc. The triangular area spanned by the three implanted markers was measured each day and normalized by the triangular area in the planning CT to allow comparisons between patients. **Results:** The correlation between the area of the seed triangle and the contoured prostate volume was measured to be roughly linear with R^2=0.63. Based on this patient population, the prostate grows in size during the first two weeks of treatment by approximately 4% and then subsequently shrinks by 7%. The crossover point occurs roughly half way through the treatment course. **Conclusion:** The triangular area spanned by three implanted fiducial markers was shown to be a reasonable surrogate to the prostate volume. Based on this surrogate, the prostate volume in 15 patients was measured to increase in the first two weeks of treatment, followed by a subsequent decrease in volume by approximately 7% over the duration of the treatment course. **Conflict of Interest:** This work is sponsored by the Elekta Synergy Research Consortium.

WE-C-J-6C-07

Dose Reconstruction and Adaptive Radiation Therapy in Prostate Cancer

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Purpose: The purpose of this work was 1.) Perform dose reconstruction for prostate patients imaged and treated with helical tomotherapy and 2.) Calculate the minimum treatment margins for non-adaptive treatment delivery. **Method and Materials:** Megavoltage CT (MVCT) images are acquired prior to each treatment fraction for prostate patients. The daily corrections were recorded for each treatment fraction and used to calculate the random positional setup errors between setup marks on the skin and internal anatomy. Dosimetric error from organ deformation was calculated by contouring the prostate, seminal vesicles, and rectum on each MVCT image. Dose volume histograms were then calculated for each fraction. In addition to the initial margin 10-mm/5-mm (*5-mm posterior, and 10-mm in all other directions*) that was used clinically, treatment plans were also created with 8-mm/4-mm, 6-mm/3-mm, 4-mm/2-mm, and 2-mm/0-mm. These treatment plans were used to assess the minimum margins that could be used for each fraction. **Results:** The total shifts from the external laser marks were measured for over 1200 treatment fractions. The standard deviation was ±4.1 mm in the AP direction, ±3.9 mm in the lateral direction, and ±2.9 mm in the SI direction. Without CT-based IGRT, an addition 6 to 8-mm of margin would be required to account for random setup variations. Treatment plans with 6-mm/3-mm of margin would have covered the prostate and seminal vesicles in 7 out of the 10 patients analyzed. Two patients would have required the 8-mm/4-mm margins, and one patient's seminal vesicles would not have been adequately covered with the 10-mm/5-mm. **Conclusion:** A dose reconstruction analysis has been performed for patients treated with CT based IGRT. Treatment margins of 6-mm/3-mm would have been acceptable for 70 percent of the analyzed patients. Patients with large fluctuations in bowel gas will require larger planning margins, even with IGRT.

WE-C-J-6C-08

Target Refixation Through Automatic Mapping Of Real-Time Surface Images With The Planning-Used Images

S Li*[1], D Liu[2], G Yin[2], J Geng[2], (1)Johns Hopkins Oncology Center, Baltimore, MD, (2)Genex Tech Inc., Kensington, MD

Purpose: to develop an accurate and precise surface-guided target refixation through optimally mapping real-time surface images with planning volume images. **Method and Materials:** An algorithm of merging the real-time surface images captured by a video camera and the simulation-planning volume images obtained through a CT or MR scanner is presented. The first concern is the systematic difference between CT/MRI skin contours and optic surface. The surface image artifacts are removed at the surface reconstruction by setting a limit on jumps at the neighboring facets. The partial-volume effect and table-patient movement in CT/MR images are corrected through comparison of the skin contours with an instant surface image without motion and partial-volume effect. The second concern is that the skin surface is not rigid and it changes with the facial expression such as opening and closing of the mouth. To capture the consistent surface images, we have added a function of continuous monitoring of facial movement. A template-based image registration and automatic surface alignment using a modified ICP algorithm have characterized the surface shape and landmarks' information and organize them into a reliable representation of the patient head position, which has lead to improve efficiency and robustness in surface-guided target localization and radiation dose delivery. **Results:** Accuracy and precision of < 1 mm and efficacy of < 1 minute have been obtained in phantom experiments and on patients in a clinical trial. **Conclusion:** By using this refixation system, one can directly transform the surface images into the planned treatment position, quickly visualize the anatomical information relative to the treatment machine, and accurately detect the target positioning error in all six degrees of freedom. **Conflict of Interest:** Authors are either consultant or employees of the camera company.

WE-C-J-6C-09

Cone Beam Digital Tomosynthesis (CBDT): An Alternative to Cone Beam Computed Tomography (CBCT) for Image-Guided Radiation Therapy

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Purpose: To investigate the feasibility of using a new imaging technique, i.e., Cone Beam Digital Tomosynthesis (CBDT) as an alternative to the Cone Beam Computed Tomography (CBCT) approach for creating 3D cross sectional images of a patient in the radiotherapy treatment room. **Method and Materials:** Similar to the CBCT approach, the CBDT uses an x-ray source (either a kV source or a MV source on a Linac or another radiation-emitting device) and an x-ray detector to acquire projection data by rotating them around a patient simultaneously. Unlike CBCT, CBDT utilizes partial scans, typically in the range of 20-60 degrees of gantry arc. The main advantage of the CBDT approach is that it takes less time to perform image acquisition and reconstruction. An experimental CBDT system has been built on a Linac with a recently developed flat-panel detector. A novel filtered backprojection algorithm was developed for CBDT reconstructions. CBDT phantom images have been generated for different degrees of gantry arc and beamline configurations and compared to those from CBCT. **Results:** Cross-sectional images of a Rando phantom were generated with comparable image quality to CBCT using as small as ~ 22 degree gantry arc. The planes of CBDT reconstruction are orthogonal to the x-ray beam at the midpoint of the arc. These reconstructed planes are of particular relevance to image-guided radiation therapy, because they depict anatomy along planes that are most relevant to the treatment beam, i.e., orthogonal to the beam axis. **Conclusion:** We have demonstrated the feasibility of using CBDT to acquire cross-sectional images of an object in the treatment room to guide radiotherapy treatment. Compared to CBCT, the CBDT approach is much faster with acceptable image quality in the planes most relevant to the treatment. **Conflict of Interest:** This work was supported by Siemens Medical Solutions USA, Inc.

Joint Imaging/Therapy Symposium Room 6B

Image-Guidance in Four Dimensions

WE-C-J-6B-01

Fast 4D Imaging: Breaking the Speed Limits in MR and CT

C Mistretta*, Univ of Wisconsin , Madison, WI

Advances in MRI and CT have made it possible to produce time-resolved series of 3D volume images. In CT the increase in detector rows to the present value of 64 - or even 256 - has brought a significant increase in image quality and reduced acquisition times. The emergence of volumetric cone beam systems employing flat panel detectors also offers the possibility of rapid 4D acquisition. In MRI, 4D sequences have been facilitated by the introduction of multi-coil parallel imaging methods and several acquisition schemes using novel k-space sampling schemes.

The vast majority of MRI applications use Cartesian acquisitions employing phase encoding. This line-by-line scan through k-pace produces spatial resolution that is linearly related to acquisition time. This is basically a k-space speed limit imposed by the Nyquist theorem. For dynamic applications this tradeoff between temporal and spatial resolution is unacceptable. When highly undersampled radial acquisitions are used, spatial resolution is determined by readout resolution rather than the number of k-space lines acquired. The price paid for violating the Nyquist theorem is streak artifacts. However, when the data acquisition is done using a time-resolved 3D radial acquisition called VIPR(Vastly undersampled Isotropic PRojection imaging), the streaks are often tolerable and have permitted acceleration factors up to 60 relative to Cartesian acquisition for applications such as phase contrast imaging where background signals are cancelled and streaks can only be generated by the vessels of interest. Undersampled cone beam acquisition using an array of x-ray sources combined with large area detectors has been proposed as a means of increasing the temporal resolution of CT and appears to have similar properties to 3D undersampled MRI acquisition.

WE-C-J-6B-02

Infrastructure for 4D Image Guide Therapy

D McShan*, Univ Michigan, Ann Arbor, MI

This presentation looks at infrastructure needed for research investigation and for routine clinical use of time resolved volumetric (4D) image guided therapy The 4D imaging data used for IGRT comes from a variety of sources ranging from standard CT scanners, cone-beam CT from gantry mounted imagers, MR, and PET images. An example of a reconstructed 4-D data set for CT would have dimensions (512x512x100x10) (100 slices per volume representing 10 different time intervals. This represents approximately 0.5 gigabytes of data. Daily acquisition of these images therefore represents significant storage demands and increased network speeds needed to communicate this data between various processes (image alignment tools, contouring/segmentation, and treatment planning). While the DICOM imaging standard can be used for storing 4D datasets, the related derive data such as deformable alignment parameters and other associated data such as statistics about anatomical variability and embedded marker positions, are beyond the standard and require establishment of separate bookkeeping to maintain that data. The actual use of 4D data varies. This data provides information about patient alignment and extent of physiological motion. However, 4D data can also provide time dependent functional information which may provide early indicators of tumor and normal tissue responses. Decision based on analysis of these functions can be employed for daily assessment and immediate adjustments to the treatment either before or during delivery. Or analysis of the 4D data may be used to provide statistical support for more deliberate plan adjustment decisions. Often 4D data implies geometrical changes over time such as heart and respiratory motion which require deformable alignment of image volumes to relate and track anatomical regions of interest between different motion states and in reference to the imaging volumes used for planning.

To aid in this presentation, a survey of current research and clinical uses of 4D image guided therapy will be presented with answers to questions regarding : the types of 4D imaging data sets used, the sizes of typical data sets, the frequency of acquisition, storage demands (long term and short term) and algorithms used for reconstruction, registration, analysis, and

compression. The survey results demonstrate infrastructure needs for 4D image guided therapy that are significantly above and beyond what is typically needed for static volumetric imaging and planning in terms of both the amounts of data acquired and the tools needed for data management and analysis, This survey has included manufacturers and leading researchers in the field. In addition to survey results, examples of the infrastructure implemented by these users will be shown.

Educational Objectives:
1. Identify various sources of 4D data and typical storage requirements
2. Present various use of 4D for IGRT employed to date and associated data display and analysis tools
3. Demonstrate successful infrastructure implementations

WE-C-J-6B-03

Use of 4D Models for Tracking Motion During Therapy

P Keall*, Virginia Commonwealth University, Richmond, VA

Patient anatomy and physiology, of both normal and tumor tissue, changes with time. These timescales vary from seconds (respiratory, cardiac and skeletal motion, rectal gas) to minutes (bladder filling, stomach emptying, muscle relation) and days (repositioning, tumor growth/shrinkage, radiation-induced effects on bronchiole obstructions, atelectasis regions, edema, fibrosis, functional reserve capacity). These changes challenge the current paradigm of three-dimensional radiotherapy methods, and demand the exploration of four-dimensional (4D) techniques to account for these intra-and interfractional changes. Several components need to be developed for 4D radiotherapy, including online volumetric imaging, automated planning, deformable model development and associated hardware and software modifications. This presentation will focus on the basis and role of 4D deformable models for tracking motion in radiotherapy. The input to 4D deformable models is volumetric imaging information (either 3D or 4D), and for some algorithms user-defined landmarks. The output of these models are displacement vector fields (DVFs), in which each anatomy element (imaging voxel) is tracked throughout the imaging data sets. These DVFs allow subsets of the anatomy, such as contours and dose distributions, to be seamlessly transferred from one dataset to another, facilitating reoptimization and accurate dose accumulation. An ideal deformable model would be (a) accurately predict DVFs (and be fail-safe where this is not possible), (b) be unsupervised and require no human input and (c) be fast to allow online implementation and use of the 4D models.

The educational objectives of this course include:
1. Appreciate the importance of 4D deformable models in radiotherapy.
2. Introduce the basis of some models that have been applied to the 4D radiotherapy problem.
3. Describe the clinical process for 4D radiotherapy using deformable models.

WE-C-J-6B-04

Panel Discussion

Panelist: C Mistretta*[1], D McShan*[2], P Keall*[3], (1) Univ of Wisconsin , Madison, WI, (2) Univ Michigan, Ann Arbor, MI, (3) Virginia Commonwealth University, Richmond, VA

Professional Symposium Room 618

Medical Physics: Regulations and Legislation

WE-C-P-618-01

Radiological Awareness Training for First Responders and Health Care Providers

J Adair*, Assistant Secretary Division of Environmental Health State of Washington

The Washington State Department of Health's Division of Environmental Health has been actively involved in providing radiological training for a broad spectrum of first responders and health care providers since 2003, through its Office of Radiation Protection (ORP). Much of the training is given by ORP staff, which also coordinates training given by outside experts. The topics include response to weapons of mass destruction (U.S. Department of Justice) and radiation emergency medical care (U.S. Department of Energy). Attendees include local public health, doctors and nurses, the Federal Emergency Management Agency, the U.S. Navy, emergency medical technicians, firefighters, hazmat responders, and law enforcement. Classes are customized for each profession, are unique and interactive, and include real radioactive materials at a mock incident scene to incorporate a sense of believability. The Department of Health's goal is to educate Washington's first responders and health care providers about the health risks from incidents involving radioactivity, both to the victims and to themselves.

Educational Objective:
1. To review the current NRC Part 35 training and experience requirements.

WE-C-P-618-02

NRC Update: Part 35 Training and Experience and Who's ACMUI and Why Should a Medical Physicist Care?

R Lieto*, St. Joseph Mercy Hospital, Ann Arbor, MI

The Nuclear Regulatory Commission (NRC) finalized the training and experience requirements for Authorized Medical Physicists, Authorized Users and Radiation Safety Officers in March 2005. A brief summary of the changes to the regulations will be presented. The Advisory Committee on the Medical Uses of Isotopes (ACMUI) was established in 1958 to advise NRC staff on policy and technical issues that arise in the regulation of the medical uses of radioactive material in diagnosis and therapy. The ACMUI membership includes health care professionals from various disciplines who comment on changes to NRC regulations and guidance; evaluate certain non-routine uses of radioactive material; provide technical assistance in licensing, inspection, and enforcement cases; and bring key issues to the attention of the Commission for appropriate action.
A general description of the ACMUI composition and interactions with NRC will be given. A discussion of the recent activities of the ACMUI and the implication for medical physicists will be presented. Future issues where NRC may have significant impact on the medical physicist will be addressed.

Educational Objective:
1. To understand the make-up and responsibilities of the ACMUI and the issues being discussed and their implications on medical physicists.

WE-C-P-618-03

CARE Act Update

D Keys*, Forest Park Hospital, Saint Louis, MO

The Alliance for Quality Medical Imaging and Radiation Therapy (of which both the AAPM and ACMP are members) met again in March 2005 to further develop, in anticipation of passage of the Care Bill, statutes designed to specify the training and experience of all medical professions performing or planning medical imaging and radiation therapy. The Bill, as written, is designed to include both Medical Physicists and Medical Dosimetrists in the proposed regulation. The CARE bill was recently reintroduced in the US congress

Educational Objective:
1. To review the current status and implications of the CARE Bill

Therapy Scientific Session Room 617

Calibration and Quality Assurance

WE-C-T-617-01

A First Step Toward a New National Standard for Direct Calibrations in Clinical High Energy Photon Beams

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Purpose: Clinical reference dosimetry for high-energy photon and electron beams is based on ion-chamber calibrations in a Co-60 beam for absorbed dose to water, as prescribed in the TG-51 protocol. A complex formalism is required when converting the calibration to the beam quality of end

users. Direct calibrations in clinical high-energy x-ray beams will eliminate the complexity and associated uncertainties, resulting in greater accuracy and measurement simplicity. **Method and Materials:** The current primary standard for absorbed dose is transferred through ionization chamber measurements in a Co-60 beam and is ultimately traceable to the first-generation water calorimeter developed at NIST by Domen. We are evaluating a new calorimeter with modern data acquisition in a Clinac 2100C photon beam at 6 MV and 18 MV. **Results:** To address the convection/conduction problems inherent to water calorimetry, we have devised a novel data-collection scheme with multiple cycles of radiation-induced temperature increase as a function of time; this has greatly improved the efficiency of measurements, thereby achieving greater precision. The temperature rise can be extracted by three approaches that yield consistent results; these will be described in detail in the presentation. The absorbed dose determined at 18 MV and 6 MV using the water calorimeter at selected depth along the beam axis are compared to the depth-dose curves measured with a calibrated ion chamber following the TG-51 protocol. In addition, the dependence of bridge-excitation voltage at the higher dose rate (4 Gy/min) behaves differently from that at a lower rate (1 Gy/min) in a Co-60 beam; this has been investigated in order to assess the influence of the thermistor power on measured results. **Conclusion:** We have obtained preliminary results and are moving toward a new national standard for direct calibrations in clinical beams.

WE-C-T-617-02

Direct Calibration of Ionization Chambers in Linac Photon Beams

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Purpose: Currently, the starting point for dosimetry in the radiotherapy clinic is an ion chamber calibrated at the standards laboratory in a ^{60}Co beam. Conversion factors obtained from a protocol such as TG-51 are then required to derive the dose in a linac beam. This paper details the measurement of these k_Q factors in photon beams from a clinical linac. **Method and Materials:** The NRC primary standard water calorimeter was used to calibrate a set of NE2571 Farmer-type ion chambers in 6, 10 & 25 MV photon beams from an Elekta *Precise* linac installed at NRC. A number of influence quantities – water purity, temperature sensors, temperature measurement system – were investigated in detail. In addition, significant effort was put into monitoring the stability of the linac to ensure that output variations did not significantly affect the measurements. **Results:** The k_Q factors obtained were in good agreement with previous measurements using the NRC Vickers research linac reported by Seuntjens *et al* in 2000. This indicates no dependence on accelerator type and validates the use of %dd10$_x$ as a beam quality specifier for megavoltage photon beams. The calculated factors given in TG-51 also agree well with these measured k_Q factors. The standard uncertainty in the calibration of an ion chamber is estimated to be 0.45%, a significant improvement over using the calculated values. **Conclusion:** A clinical linac can be successfully used for primary standards dosimetry. Absorbed dose calibration factors for a set of NE2571 chambers have been obtained for 6, 10 & 25 MV photon beams. Factors for other chambers can be determined by direct comparison with these reference chambers in a water phantom.

WE-C-T-617-03

Dosimetry of Beta Emitting Intravascular Brachytherapy Sources

S Treis*, L DeWerd, J Micka, University of Wisconsin Medical Radiation Research Center, Madison, WI

Purpose: To verify the accuracy of current intravascular brachytherapy (IVBT) Sr-90 calibration standards and to generate accurate and detailed IVBT beta dosimetry by analyzing dose distributions in a liquid water medium **Method and Materials:** High Sensitivity radiochromic film as well as lithium fluoride thermoluminescent dosimeter (TLD) 1x1x1mm microcubes were exposed in liquid water to a Novoste Beta-Cath Sr-90 IVBT source pellet. Calibration exposures were performed with a Tracerlab RA-1 Sr-90/Y-90 ophthalmic applicator directly traceable to the National Institute of Standards and Technology (NIST) absorbed dose to water standard. Film and TLDs were read 24 hours post-exposure using a Molecular Dynamics Personal Densitometer SI scanner (633nm HeNe laser light source) and a Harshaw 5500 unit, respectively. All exposures were made in a custom built water tank with computer controlled high precision Velmex tracks providing three axes for movement of measurement devices. **Results:** Preliminary radial depth dose measurement results with film and TLDs correspond within uncertainty estimates to data published by Soares et al, which is the current NIST standard for IVBT beta sources. The TLDs showed significant volume averaging over their 1mm thickness, requiring Monte Carlo correction to determine the effective point of measurement for each dosimeter. **Conclusion:** Liquid water measurements of IVBT beta dosimetry validate the results from previously published studies conducted solely in plastics and in air. These measurements also reduce experimental uncertainty by eliminating the conversion to water from data taken in water mimicking media.

WE-C-T-617-04

Absolute Calorimetric Calibration of I-125 and Pd-103 Brachytherapy Sources

K.E. Stump*, L.A. DeWerd, University of Wisconsin, Madison, WI, Department of Medical Physics, Madison, WI

Purpose: To develop an absolute method of low energy, photon-emitting brachytherapy source strength specification that provides high precision and high accuracy measurements in terms of both the total contained and emitted power of the source. **Method and Materials:** A cryogenic calorimeter has been developed utilizing high temperature superconducting transition edge sensors as thermometers. The instrument is capable of providing direct measurements of the total source power as well as only the fraction that is emitted by the source. The calorimeter makes use of the well-established electrical substitution principle to provide a direct measurement of power. With this method, a temperature control feedback loop is used to maintain a thermometer resistance set point in the center of the thermometers' superconducting transition. The heater power required to maintain this set point is compared both with and without the source present. The difference between the two heater powers is the measurement of source power. **Results:** Preliminary contained power measurements made with the calorimeter demonstrate a precision of approximately 0.5%. The power measurements are compared to air kerma strength measurements by means of Monte Carlo calculations. Using this method, agreement between the measurements is within 1.5%. The calorimeter has a demonstrated noise floor of 2 nW. Current work is focused upon evaluating an improved detector design and performing contained power and emitted power measurements of several different source types and strengths. **Conclusion:** The initial measurements with the calorimeter indicate that it is possible to provide high precision, high resolution power calibrations of brachytherapy sources. Features of this method are that no conversion factors are used to arrive at the desired quantity and few correction factors are required. Current work is focused upon evaluating an improved detector design and performing contained power and emitted power measurements of several different source types and strengths.

WE-C-T-617-05

The Effects of Aperture Size On Low-Energy Brachytherapy Sk Measurements

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Purpose: To experimentally determine the angular dependence of ^{125}I and ^{103}Pd interstitial brachytherapy seed air-kerma strength measurements with a large-volume ionization chamber and compare with Monte Carlo calculations. **Method and Materials:** A Variable Aperture Free Air Chamber (VAFAC) has been constructed for making air-kerma rate measurements of low-energy photon emitting sources with photon energies up to 70 keV. Its underlying principle is that the air-kerma rate at a given point is proportional to the increment of ionization per increment of chamber volume at chamber depths greater than the range of secondary electrons originating in the entrance electrode. A unique feature of the VAFAC is its variable aperture stand, which accommodates five apertures with half angles ranging from 4 to 18 degrees. The US primary air-kerma strength standard is the National Institute of Standards and Technology Wide Angle Free Air Chamber (NIST WAFAC), which has a single fixed aperture size corresponding to a half-angle of 7.6 degrees. Relative air-kerma rate measurements have been completed for one seed type with all five aperture sizes. Additionally, MCNP5 particle transport has been used to theoretically determine the expected relative ionization with these aperture sizes. **Results:** It is shown that the new VAFAC is capable of making air-kerma rate measurements for low-energy brachytherapy sources with a noise floor of 1-2 fA. The results from the first seed type indicate

that varying the angle from 4 to 18 degrees yields up to a 5% change in the final air-kerma strength determination. **Conclusion:** This work shows the capability of the VAFAC to experimentally measure the effects of ^{125}I and ^{103}Pd interstitial brachytherapy seed in-air anisotropy on a large angular measurement.

WE-C-T-617-06

Spectral Reconstruction by Scatter Analysis

Dr. Wassim Jalbout, American Univ of Beirut, Beirut, Lebanon

Purpose: To reconstruct accelerator photon beam energy spectra by *scatter analysis*. **Method and Materials:** The method consists in irradiating a plastic phantom at standard 100cm SSD and inferring primary beam spectral information based on the measurement with a standard Farmer chamber of scatter around the phantom at several specific scatter angles: a *scatter curve* is measured which is characteristic of the primary spectrum at hand. A Monte Carlo code is used to simulate the scatter measurement setup and predict the relative magnitude of scatter measurements for mono-energetic primary beams. Based on mono-energetic primary scatter data, measured *scatter curves* are analyzed and the spectrum unfolded as the sum of mono-energetic individual energy bins using the Schiff bremsstrahlung model. In comparison with spectral reconstruction by attenuation analysis, scatter is shown to be a measurable quantity that varies steeper with primary photon energy than attenuation does, providing the potential for a better resolving of adjacent energy bins within the spectrum. **Results:** The method is applied to an Elekta/SL18 6MV photon beam. The reconstructed spectrum matches the Monte Carlo calculated spectrum for the same beam within 6.2% (average error when spectra are compared bin by bin). Depth dose values calculated for the reconstructed spectrum agree with physically measured depth dose data to within 1%. **Conclusion:** The method has potential as a practical spectral reconstruction tool requiring few measurements under standard 100cm SSD and feasible in any radiotherapy department equipped with a conventional plastic scattering phantom and Farmer chamber.

WE-C-T-617-07

Using X-Ray Spectrometry to Quantify the Effects of Emission Anisotropy On Air-Kerma-Strength Measurements of Prostate Brachytherapy Seeds

M Mitch*, S Seltzer, National Institute of Standards and Technology, Gaithersburg, MD

Purpose: To utilize the results of prostate brachytherapy seed x-ray spectrometry to quantify the effects of emission anisotropy on air-kerma-strength measurements. **Method and Materials:** Air-kerma strength was calculated from x-ray spectra measured with a high-purity germanium detector with the seed rotated at 90-degree intervals about an axis perpendicular to the mid-point of the long axis of the seed. The "air-anisotropy ratio", α_S, was formed by taking the quotient of the air-kerma strength of the seed with the long axis perpendicular to the detector face and the air-kerma strength of the seed with the long axis parallel to the detector face. The resulting quantity α_S is a quantitative measure of in-air anisotropy, which has a significant effect on the relative responses of secondary-standard well chambers and the National Institute of Standards and Technology (NIST) Wide-Angle Free-Air Chamber (WAFAC) primary standard. **Results:** Values of α_S for various seed models are influenced by the presence of end welds, seed internal geometry, and the incorporated radionuclide. In comparing α_S among seeds, a lower value indicated that the output of the seed was more directional (along the transverse axis), such that less emission was "missed" by the WAFAC (8 degree half-angle) that was detected by the well chamber (approximate 4π geometry). **Conclusion:** The quantity α_S has proven to be a useful parameter for explaining differences in well-chamber response observed for different seed models having the same emergent spectrum on their transverse axis. It also has been used to identify aberrantly produced seeds that are not representative of those calibrated previously by NIST. Characterization of seed anisotropy is necessary in order to maintain accuracy in the transfer of air-kerma-strength standards from NIST to the AAPM Accredited Dosimetry Calibration Laboratories and to seed manufacturers.

WE-C-T-617-08

Beam Hardening and Implications for Dose Calibration of An A-Si EPID

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Purpose: This work aims to quantify and minimize a dose calibration curve discrepancy observed for an a-Si flat panel megavoltage imager that occurs when the spectral quality of a lower energy (6 MV) beam is changed from that for an open field due to beam hardening. **Method and Materials:** This investigation considered a Varian aS500 EPID. In the first phase, Monte Carlo simulations modeled spectral changes to a generic 6 MV photon beam as it passed through different thicknesses of steel shot compensator material. A comprehensive model of the detector was also used to simulate the dose absorbed by the integral phosphor layer for the conventional detector configuration, and for configurations including an additional, external copper plate placed in direct contact with the EPID and elevated 154 cm above it. The second phase consisted of measuring EPID dose calibration curves in open and steel-shot attenuated beams for the various EPID configurations. The modulation transfer function (MTF) and the contrast-to-noise ratio (CNR) were also monitored for each configuration using a standard quality assurance phantom. **Results:** The discrepancy between open and attenuated beam calibration curves was observed to be as much as 6% at 6 MV. To reduce the maximum discrepancy to < 4%, copper thicknesses of 1.0 cm or 0.3 cm were required in the contact and elevated configurations, respectively. Adding the copper reduced the CNR by 28% or 8%, respectively, and the MTF for a given spatial frequency by 38 ± 1% or 13 ± 1%, respectively. **Conclusion:** Beam hardening can cause significant dosimetric discrepancies for a-Si EPIDs calibrated in open fields. Addition of an external copper plate can substantially reduce the discrepancy, but at a cost of reduced image quality.

WE-C-T-617-09

The Radiological Physics Center's Anthropomorphic Quality Assurance Phantom Family: New Developments

D Followill*, J Lowenstein, A Jhingran, J Roll, N Hernandez, G Ibbott, UT M.D. Anderson Cancer Center, Houston, TX

Purpose: To develop quality assurance (QA) phantoms that simulate specific treatment sites for the purpose of credentialing institutions for participation in NCI-sponsored advanced technology clinical trials. **Method and Materials:** The Radiological Physics Center (RPC) has developed an extensive credentialing program for institutions wishing to participate in clinical trials that use advanced technologies such as IMRT. This program includes questionnaires and irradiation of an anthropomorphic QA phantom specifically designed for the trial. These QA phantoms typically are water-filled plastic shells with imageable targets, avoidance structures, and heterogeneities that contain TLD and radiochromic film dosimeters. Three new trials are presently under development; 1) extracranial stereotactic radiotherapy for liver metastases, 2) IMRT for endometrial or cervical cancer and 3) advanced RT for mesothelioma. New phantoms or target/dosimetry inserts have been designed to meet the credentialing needs for the three trials listed above. **Results:** A new liver phantom has been designed and constructed. The liver phantom contains two targets within the liver and three organs at risk (OAR); the stomach, kidney and spine. This phantom will be placed on a 2D reciprocating table to include target motion in the AP and SI directions. A new target/dosimetry insert has been designed for the RPC's existing thorax phantom that will include an OAR for the liver and dosimeters in the lung and in the chest wall. Finally, another target/dosimetry insert has been designed for the pelvic phantom that will include a vagina, cervix, bladder and rectum. **Conclusion:** The RPC has been and will continue to be proactive and responsive to the needs of the study groups as new treatment modalities are used for new clinical trials.

This work was supported by PHS grant CA10953 and CA081647 awarded by NCI, DHHS.

WE-C-T-617-10

Geometry Calibration of An On-Board KV Imaging System

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Purpose: We have developed a method of geometrically calibrating the MV and kV radiographic isocenters of a Varian linear accelerator equipped with an on-board kV imaging system. **Method and Materials:** The calibration uses a cylindrical phantom containing 16 BB's placed in a spiral pattern and ~400-600 radiographs of the phantom acquired using both kV and MV imaging systems. Since the phantom has a known geometry, the 7 degrees of freedom (DOF) needed to fit the predicted projections of the BB's to the measured projections can be calculated. During MV imaging a partial transmission plate is placed in the accelerator wedge slot to project a reference shape onto the EPID images of the phantom. The reference shape accounts for motion of the EPID and generates the radiographic isocenter for the MV x-ray beam alone. Geometry correction parameters can be calculated for the kV imaging system that map the center of radiographic images or CBCT projections to the radiographic isocenter of the MV beam. The method has been tested with linear accelerator and lab bench imaging systems. **Results:** BB identification accuracy is ~0.3 pixels and is limited by noise in the images. While the method is insensitive to changes in SID (0.3 pixels ~= 2.5 cm SID change), the method can measure known in-plane imager displacements to an accuracy of better than 0.1 mm. Imager displacements versus gantry angle are small - 0.75x0.50 mm. CBCT reconstruction using parameters from this method results in spatial frequencies as high as 18 lp/cm and adjustments in parameters of ±0.1 mm reduce the reconstructed spatial resolution. **Conclusion:** Our method to match MV and kV radiographic isocenters for on-board imaging systems shows that accelerator flex is quite modest but that the calibration method can improve the spatial resolution of the CBCT reconstructions.

Therapy Symposium Room 6E
Nanotechnology and Cancer

WE-C-T-6E-01
Introduction
E Yorke*, Memorial Sloan-Kettering Cancer Center, New York, NY

WE-C-T-6E-02
Introduction
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WE-C-T-6E-03
Superparamagnetic Nanoparticles for Brain Tumor Diagnosis and Therapeutics
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Gliomas are currently the most common and lethal type of primary brain tumor. Treating malignant gliomas remains a formidable challenge due to the difficulty in differentiating between tumor and healthy brain tissue, the rapid growth rate of invasive gliomas, intrinsic cellular resistance of gliomas to drugs, and the blood brain barrier (BBB) preventing the passage of drugs and contrast agents. My talk will describe our recent work in the development of a multifunctional nanoprobe for targeting glioma tumors by conjugating iron oxide nanoparticles with a glioma tumor targeting molecule and a near infrared fluorescing (NIRF) molecule. The nanoprobe is detectable by both magnetic resonance imaging and fluorescence microscopy, and exhibits significant targeting capability to glioma cells and effective inhibition to glioma cell migration. Our results demonstrate a cellular-level resolution that may promise accurate delineation of otherwise poorly defined glioma interfaces resulting from their highly invasive morphology. The application of the nanoprobe for preoperative and postoperative diagnostic imaging with MRI and the real-time intraoperative visualization of tumor margins with optical devices is a novel approach to improve the effectiveness of diagnostic and therapeutic modalities available for brain tumor patients.

WE-C-T-6E-04
Nanotechnology for Molecular Imaging
G Lanza*, Washington University Medical School, St. Louis, MO

Developments in molecular science are pushing the temporal detection horizon of medical diagnosis and therapy back from the anatomical sequelae of disease to its earliest physiological and biochemical manifestations. The emerging field of "Molecular Imaging" may be envisioned as the *in vivo* diagnosis of complex pathological processes by detection of unique biochemical signatures. The concept is analogous to microscopic detection of specific epitopes with immuno-histochemistry techniques translated into a complex and hostile *in vivo* environment and detected with noninvasive medical imaging systems.

We have developed a novel multi-modal site-targeted contrast agent for sensitive and specific imaging of molecular epitopes and local therapy. This "platform" approach comprises a nanoparticle that is applicable to at least three common noninvasive imaging modalities: ultrasound (native particle), magnetic resonance (gadolinium conjugated), and nuclear imaging (radionuclide conjugated). Homing ligands linked to the surface of the nanoparticle an injectable agent with long circulating half-life and high signal amplification upon binding to a molecular target. This novel platform has been used to detect angiogenesis, fibrin, tissue factor and collagen III and to locally deliver therapeutic agents through a unique contact facilitated mechanism. Over the next decade, molecular imaging, in conjunction with rational targeted therapies, will likely change many clinical paradigms in medicine.

WE-C-T-6E-05
NEXGEN Restorative Health Care Thru Synthetic Biology and Nanoscience
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Recent advances in our ability to manipulate matter at the scale of individual molecules have created an incredible level of excitement in both the scientific community and the general population. The excitement over this new capability, commonly labeled nanotechnology, is vested in the expectation of the development of new materials and systems that offer unparalleled functionality. Materials that autonomously adapt their shape and physical properties in response to the their surroundings, computers that instead of operating by switching the flow of electrons, manipulate information through the management of the ethereal world of quantum states and, molecular sized machines that actively repair damage to our bodies and function as molecular scale prosthetics are all expectations of nanotechnology. While the question of whether or not this vision is truly achievable is still open, the truth is that much of the expectations for nanotechnology are already realized in living systems.
Living systems however, are more than a product of matter manipulation at the molecular scale; the richness of functionality associated with living systems is a direct product of the information generated from both the interactions between molecules and the overall supra-molecular structure of the system. In essence living systems are "living" because of the fusion of nanotechnology and informatics. Living systems result from the precision assembly of matter with prescribed modalities for the transport and transduction of information among supra-molecular clusters.
Recent advances in surgical and diagnostic tools emanating from nanotechnology will be presented in the context of Integrative Technology. Integrative Technology is the intersection of the precision assembly of matter, nanotechnology, coupled with the functional building blocks of nature, biotechnology, fused by the network flow of spatiotemporal information, informatics. The power of Integrative Technology is illuminated through the creation of Synthetic Biological Systems. Hybrid biotic/abiotic systems that enable the restoration of loss biological function thru designed communication among supra-molecular assemblies. Illustrative examples will be presented that include the engineering of muscle-powered Biobots and the creation of nano-sized excitable vesicles with the ability to intrinsically process information. These devices have the potential of replacing lost biological function in physiologic structures such as the Sinoatrial node or damaged neurons, and highlight a new modality for disease therapy. Technology that will expand surgical applications beyond the arena of structural repair to the realm of physiological manipulation.

Imaging Scientific Session Room 6B
In-Room Imaging for Radiation Therapy

WE-D-I-6B-01

Soft Tissue Visualization Using a Highly Efficient Megavoltage Cone Beam CT Imaging System

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Purpose: Recent developments in two-dimensional x-ray detector technology have made volumetric Cone Beam CT (CBCT) a feasible approach for integration with conventional medical linear accelerators. The requirements of a robust image guidance system for radiation therapy include the challenging combination of soft tissue sensitivity with clinically reasonable doses. Previously, low contrast objects have generally not been perceptible with MV energies due to relatively poor signal to noise ratio (SNR) performance. We have developed an improved imaging system that is optimized for MV CBCT and acquire CBCT images containing soft tissue contrast using a 6MV x-ray beam. **Method and Materials:** Many factors, such as image noise, x-ray scatter, improper calibration and acquisitions have a profound effect on the imaging performance of CBCT. In this study attempts were made to optimize these factors in order to maximize the SNR. A QC-3V and contrast/resolution phantoms were used to determine the contrast to noise ratio (CNR) and f_{50} of a single 2-D projection and the contrast and spatial resolution of the reconstructed images. **Results:** The computed f_{50} was 0.43 lp/mm and the CNR for a radiation dose of 0.02cGy was 43. Relative electron density as low as 1% can be resolved with clinically reasonable radiation doses. Clinical Megavoltage CBCT images acquired with this system demonstrate that anatomical structures such as the prostate and optic nerves are visible using radiation doses in range of 4 to 8cGy. **Conclusion:** We have developed an imaging system that is optimized for MV and acquire Megavoltage CBCT images containing soft tissue contrast using a 6MV x-ray beam and irradiation doses in range of 4 to 8cGy. This system can also be used for routine portal imaging applications without risk of saturation for high dose/high energy treatment/verification imaging, or dosimetry applications.
Conflict of Interest : Sponsored by Siemens

WE-D-I-6B-02

High DQE Megavoltage Imaging Using Active Matrix Flat-Panel Imagers Incorporating Polycrystalline Mercuric Iodide

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Purpose: In order to explore the potential for significantly improving the DQE of megavoltage active matrix flat panel imagers (AMFPIs), two forms of thick, polycrystalline mercuric iodide (HgI_2) photoconductors have been investigated. **Method and Materials:** Prototype direct-detection AMFPIs with an effective pitch of 508 μm and a pixel format of 192×192 were coated with two types of HgI_2: a "PVD" form created through physical vapor deposition and a "PIB" (particle-in-binder) form involving screen-printing. Results were compared to those from a conventional indirect-detection megavoltage AMFPI employing a phosphor screen. Data were obtained fluoroscopically, using a 6 MV beam at very low doses, equivalent to ~0.004 to 0.04 cGy. **Results:** Compared to PVD, the PIB array exhibits much lower dark current, lower dark drift, slightly higher lag and similar non-uniformity, linearity and DQE. For both PVD and PIB, MTF and DQE results are in a good agreement with theoretical expectations, and the MTF is higher than that from the conventional megavoltage AMFPI. Moreover, the DQE results show input-quantum-limited behavior, even at very low doses. Finally, zero-frequency DQE values are ~1.4% and 1.2% for PVD and PIB, respectively, matching the theoretical upper limits for the thickness of the converters used. Given the modest photoconductor thickness of these early prototypes, the DQE values compare favorably to values of ~1% obtained from conventional megavoltage AMFPIs. **Conclusion:** These initial studies indicate that AMFPIs incorporating polycrystalline HgI_2 have the potential for significant dose reduction in megavoltage imaging. The use of HgI_2 offers the promise of increased quantum efficiencies through the development of substantially thicker converters than have thus far been achieved, without significant degradation of the spatial resolution. In addition, compared to PVD, PIB appears to provide better prospects for such thick coatings, leading to higher DQE. This work is supported by NIH grant R01-CA51397.

WE-D-I-6B-03

The Role of Secondary Photons in the Quantum Absorption Efficiency of Megavoltage X-Ray Detectors: Is Dmax the Ideal X-Ray Converter Thickness?

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Purpose: To quantify the impact of x-ray converter thickness and determine the role of secondary photons on the quantum absorption efficiency of megavoltage x-ray detectors (metal plate/phosphor screen) used in portal imaging and megavoltage CT. **Method and Materials:** The Electron Gamma Shower (EGSnrc) Monte Carlo code was used to simulate the coupled photon-electron transport within a copper (Cu) metal plate / gadolinium oxysulphide phosphor screen detector. The DOSRZnrc user code was used to score the spectrum of x-ray energy deposition within the phosphor layer of the detector. In the simulations, a wide range of metal plate thicknesses (0–60 mm), phosphor screen thicknesses (0.1–5 mm), and incident photon energies (1–10 MeV) were investigated. The quantum absorption efficiency (QAE) was calculated from each absorbed energy distribution (AED) simulation. **Results:** Plots of QAE versus copper metal plate thickness indicate: the maximum QAE does not occur at the depth of maximum dose (d_{max}), but rather for a thicker metal plate; the metal plate thickness corresponding to maximum QAE increases with phosphor thickness; the magnitude of the QAE increases with phosphor thickness; and the maximum QAE is independent of the incident photon energy. For example, for a 1 MeV incident photon energy and 1 mm phosphor thickness, a factor of two improvement in the QAE can be achieved using a 12 mm thick metal plate. **Conclusion:** Our results suggest that using thicker metal plate converters can increase the QAE of megavoltage x-ray detectors. This improvement in QAE can potentially lead to reductions in patient dose for megavoltage imaging. Furthermore, in terms of maximizing the QAE, higher order Compton scattered and pair annihilation photons that originate in the metal plate play a more important role than primary electrons.

WE-D-I-6B-04

Extracting CT Data in An Image-Guided Radiotherapy Benchtop Where Continuous Radiation Contaminates Image Data

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Purpose: A subtraction technique is used to extract kilovoltage computed tomograpy (kVCT) image information from a data set that has the combined response from imaging and treatment radiations. This data acquisition problem addresses an imaging/radiotherapy system that has a source that cannot be pulsed, i.e. a radioactive source. **Method and Materials:** A benchtop image-guided radiotherapy system uses a single CT detector and data acquisition system for imaging and treatment verification. The treatment radiation exposes every data collection cycle (DCC) and image radiation exposes every other DCC. Hence, sequential DCC alternates between the detector response from only the treatment radiation and the combined response from both the imaging and treatment radiations. To isolate the detector response from the imaging radiation, the image data set is produced from the subtraction of adjacent DCC. To demonstrate the effectiveness of this subtraction technique, CT images produced from this extracted data (extract-CT) are compared to conventional kVCT images. **Results:** Images of simulated tissue equivalent cylinders from the extract-CT and kVCT are similar. However, when comparing regions of uniformity, the standard deviation in pixel values are noticeably lower in kVCT. In extract-CT, the standard deviation of pixel values in tissue equivalent trabecular bone, liver, breast, and adipose are respectively 7.1%, 5.3%, 31%, and 36% higher than kVCT. **Conclusion:** A dual-source synchronization and data extraction method demonstrates that only a single detector and data acquisition system is required for a combined imaging/ radiotherapy system. The subtraction method presented in this work compensates for continuous radiation contamination of imaging data. However, the image quality is still compromised when compared to images without contamination.
Conflict of Interest: This work was partially supported by grant from the NIH (PO1 CA088960) and a contract from TomoTherapy Inc.

WE-D-I-6B-05

A Technique for Respiratory-Gated Radiotherapy Treatment Verification with An EPID in Cine Mode

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Purpose: Many clinics are performing respiratory-gated treatment based on external surrogates. Verification of these treatments is very important for ensuring the delivery of the planned dose distribution. **Method and Materials:** We have developed a new technique for treatment verification using an Electronic Portal Imaging Device (EPID) in *cine* mode for gated 3D conformal therapy. Implanted radiopaque fiducial markers inside or near the target are required for this technique. The markers are contoured on the planning CT set, enabling us to create Digitally Reconstructed Radiographs (DRR's) for each treatment beam. During the treatment, a sequence of EPID images are acquired without disrupting the treatment. Implanted markers are visualized in the images and their positions in the beam's-eye-view are calculated off-line and compared to the reference position by matching the field apertures in corresponding EPID and DRR images. The precision of the patient setup, the placement of the beam-gating window, as well as the residual tumor motion can be assessed. This technique has been demonstrated in a case study, with three implanted markers. **Results:** For this patient, the intra-fractional variation of all marker positions in the gating window has a 95% range of 4.8 mm in the SI direction (the primary axis of motion). This is about the same (5 mm) as the residual motion considered in the planning process. The inter-fractional variation of the daily mean positions of the markers, which indicates the uncertainty in the setup procedure, is within +8.3/-4.5 mm (95% range) in the SI direction. **Conclusion:** The proposed technique will be used for gated treatment verification. The results of many cases will help us determine appropriate treatment margins for gating. **Conflict of Interest:** This work was supported, in part, by a grant from Varian Medical Systems, Inc.

WE-D-I-6B-06

Development and Analysis of a High Quantum Efficiency Thick Scintillator Based Video EPID for Sub-MU Verification Imaging

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Purpose: The major limitation of current electronic portal imaging devices (EPIDs) is poor quantum efficiency (QE) with less than 5% of incident radiation being typically detected. We present a high QE prototype EPID based on a CsI(Tl) thick scintillation crystal (TSC) for high quality sub-MU verification imaging. **Method and Materials:** The prototype TSC utilizes a 12 mm thick clear 17X17cm2 CsI(Tl) screen (QE=24%) coupled to a 12-bit, 1024X1240 Plumbicon-tube camera (250 μm pixel-size at isocenter) installed on a clinical Siemens BEAMVIEWPLUS gantry. The initial performance of the TSC was studied with experimental measurements of spatial resolution and noise, along with a quantum accounting diagram (QAD) based on linear cascaded systems theory to predict system detective quantum efficiency (DQE). The theoretical model was used to study the effect of various components of the detector geometry on image quality, and to optimize the TSC for improved image quality. **Results:** The current TSC prototype with DQE(0)~0.01 provides an order-of-magnitude improvement in image quality over traditional VEPIDs, while matching the performance of flat-panel imagers at low frequencies. Since the optical geometry of the BEAMVIEW gantry was not optimized for the TSC, there was some loss in spatial resolution resulting in diminished performance at high frequency. Overall good image quality was observed even at low exposures. **Conclusion:** The enhanced luminescent output of the TSC results in high quality portal images even at sub-MU dose, and significant potential for daily verification imaging without risk of additional patient dose and intra-treatment imaging to monitor patient motion. Proposed improvements in the TSC include the optimization of the detector geometry for greater light collection efficiency and spatial resolution. Based on the QAD model, the performance of the TSC with proposed improvements is expected to improve significantly (DQE(0)~0.1) and exceed that of current flat-panels.

WE-D-I-6B-07

Human and System Error Analysis of a 3D Optical Laser Scanning System for Image-Guided Patient Positioning

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Purpose: The final goal of this research is to develop a patient repositioning system using a 3D optical laser scanner. We investigated the magnitude of human and system errors, which determines the accuracy of the patient repositioning system. We also scanned four breast patients to test the efficacy of this system. **Method and Materials:** A handheld 3D surface scanning system acquires patient surface images, which are registered to a reference image using a rigid body transformation. The resultant image registration generates the patient position adjustment to match the images. We evaluated human and system error associated with this positioning technique. To measure human error, ten operators performed ten experiments to acquire the same reference point. To evaluate the system error, we attached the receiver (serving as the origin of the surface image data) to the X-Y-Z positioning system and measured the discrepancy between the measured physical position and the scanner reported distance in three axes. We also scanned four breast patients and analyzed the repositioning errors. **Results:** The mean human error and standard deviation were evaluated to be 1.86mm and 0.66mm, respectively. The system mean error and standard deviation were found to be 0.4mm and 0.32mm (n=45), respectively. Image translation and rotational shifts from the patient study ranged from 5mm to 15mm and –6° to 11°, respectively. **Conclusion:** We have experimentally evaluated human and system error associated with a new 3D hand-held laser scanner positioning system. As shown in the result, human error was much more significant than system error. This handheld 3D optical scanning system has proved its capability as a tool for patient repositioning between fractions. Future investigations will examine the relation between surface images and internal target localization.

WE-D-I-6B-08

Deformable Registration of the Planning Image (KVCT) and Daily Treatment Images (MVCT) for Adaptive Radiation Therapy

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Purpose: The incorporation of daily images into the radiotherapy process leads to Adaptive Radiation Therapy (ART), in which the treatment is evaluated periodically and the plan is adaptively modified during the whole course of radiotherapy. Deformable registration between the planning image (usually KVCT) and the daily image is the key component of ART. The MVCT is one of the most informative yet convenient daily image modalities. In this presentation, we developed a fast technique for deformable registration between the KVCT image and the MVCT images. **Method and Materials:** The method is extended from the state-of-art deformable registration technique, which is fast and accurate for same modality registration. Considering the higher noise and lower contrast nature of MVCTs, special techniques such as "edge-preserving smoothing" and "reference based histogram calibration" are applied before the deformable registration process. The whole process is around 2-3 minutes for typical MVCT size (256x256x64) when runs on a single processor PC. We retrospectively studied daily MVCTs from commercial TomoTherapy machines in different clinical centers. These data include 3 lung cases, 5 head-neck cases, 3 prostate cases and 2 pelvis cases. Each case has one KVCT image and 30-40 MVCT images. We registered the MVCT images with their corresponding KVCT image. **Results:** The similarity measures and visual inspection of contour matches by physicians validate this technique. The applications of deformable registration in ART, including "accumulative dose calculation", "automatic ROI re-contouring" and "tumor growth/shrinkage monitoring" through the whole course of radiotherapy are studied. **Conclusion:** Deformable registration between the KVCT and MVCT images is an essential step towards ART. Through the combination of conventional image processing techniques and the fast intensity based deformable registration, such task becomes feasible. Extensive tests based on the daily MVCT data from the TomoTherapy machines validate such technique. Several key components of ART are developed.

WE-D-I-6B-09

Tracking Prostate Motion and Isocenter Offset During Treatment Using the Calypos(tm) 4D Localization System

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Purpose: To evaluate use of a real-time tracking system to determine intrafraction prostate motion and isocenter offset. **Method and Materials:** Calypso® 4D Localization System ("Calypso System", Calypso Medical, Seattle, WA) is a patient positioning device to be used as an adjunct for radiation therapy. Calypso System includes implanted markers (Beacon® transponders) and external electronics consisting of a movable console and electromagnetic array, user interface, infrared cameras, and tracking station. The external electronics continuously localize the implanted transponders using electromagnetic signals. Treatment target position offsets are computed based on transponder and isocenter coordinates from CT scans.
In a pilot study at two centers, 11 patients were tracked during an 8-minute session. In a follow-on study at five centers, tracking data will be acquired during radiation delivery in 30 patients. Patients enrolled on study are seeking radiation therapy for prostate cancer and have three transponders implanted into the prostate gland. Patients are set to skin marks and then adjusted using the Calypso System for final alignment for radiation delivery. Organ motion and isocenter offset will be tracked during treatment. If the isocenter offset exceeds a user-established limit during the fraction, the therapist will realign the patient using the Calypso System user interface. **Results:** Tracking sessions were performed on 11 patients to date. Two of the 11 patients showed significant organ motion (>1 cm) over an 8-minute period. The longitudinal and vertical motion followed the same pattern of change, while no significant motion was detected in the lateral direction. The excursions persisted for over one minute. **Conclusion:** Tracking of the prostate showed significant motion over time periods of interest in radiation therapy in some patients. Tracking of organ motion has the potential to play an important role in IMRT and other conformal radiation treatments.

Financial interest in Calypso Medical Technologies, Inc.

Imaging Scientific Session — Room 609

Small Animal Imaging

WE-D-I-609-01

Design and Calibration of a Robotic Needle Positioning System for Small Animal Imaging Applications

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Purpose: A needle-positioning robot is being developed for three-dimensional micro-ultrasound guided interventions. This device will be used to perform minimally invasive injections and biopsies into small animals with high accuracy and precision. **Method and Materials:** The robot has three degrees of freedom for positioning the needle in three dimensions. Two rotational joints are used to control needle orientation (roll and pitch). Another joint linearly translates the needle to perform insertion. The design features a four-bar linkage mechanism that translates the roll axis of rotation from an actuator to a remote axis that intersects the pitch and needle axes. The three intersecting axes create a remote center of motion (RCM) that acts as a fulcrum for the three-dimensional orientation of the needle. The RCM corresponds to the insertion point of the needle into the animal. In order for the robot to achieve high accuracy, it must be calibrated to ensure that the three axes intersect at a single point, and the needle tip must be positioned at the RCM. The calibration was performed using a macro lens CCD camera to find the center of rotation about the pitch and roll axes separately. The position of the needle was adjusted until it was aligned with the RCM. **Results:** The range of motion is ±30º, ±45º, and 20 mm for the pitch, roll, and needle axes, respectively. Initial calibration results indicate that the distance from the needle to the pitch and roll axes are 24 ± 30 μm (mean ± standard deviation of five trials) and 18 ± 15 μm, respectively. The pitch and roll axes are separated by 11 ± 3 μm. **Conclusion:** The expected maximum needle positioning error computed from the calibration results is 32 μm when the needle tip is moved to the boundary of the workspace.

WE-D-I-609-02

Characterization of a Novel Dual-Panel PET Scanner for Use in Small Animal Imaging

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Purpose: Characterization of a novel dual-panel PET scanner for use in small animal imaging. **Method and Materials:** A prototype PET system comprised of two non-rotating HRRT panel detectors – each possessing a single-layer 72 x 104 array of 2.1mm x 2.1mm x 7.5mm LSO crystals – was evaluated for its suitability in small animal imaging. Resolution measurements were made by translating a 190mm long, 3mm diameter 21.5MBq ⁶⁸Ge line-source across various planes parallel to the detector's face, while sensitivity measurements were made in a similar fashion but using a 0.5mm diameter 65KBq ⁶⁸Ge point-source. To emulate small animal imaging, a mouse phantom was constructed from an 11.25mm length of 25.4mm diameter polycarbonate rod that contained a 3.5mm diameter hole – radially offset by 6.7mm and parallel to the rod's central axis – to accommodate either the ⁶⁸Ge line-source or ¹⁸FDG samples. **Results:** Activity-independent scattered fractions were estimated by inserting the ⁶⁸Ge line-source into the mouse phantom, averaging counts in each crystal column parallel to the line-source, and second-order polynomial fitting the resulting projection data after excluding its central peak. Noise Equivalent Count Rates (NECRs) were then derived for various energy windows and ¹⁸FDG activities in the mouse phantom, to quantify scanner performance. Preliminary image reconstructions, performed using a 50-iteration Expectation Maximization algorithm, demonstrated reconstruction resolutions of ~1.6mm. Sensitivity measurements exhibited significant dependence upon energy window selection; with the 250-750keV energy window resulting in both the highest absolute sensitivity (6.8%) and the highest NECR (142kcps at 1.25MBq/cc). **Conclusion:** Although the measured sensitivity's energy dependence suggests additional energy calibrations are needed, preliminary data show both device sensitivity and resolution to be comparable to or better than that of current commercial systems. Moreover the dual-panel scanner's simple fixed geometry and large field-of-view are especially well suited for whole-body imaging and concurrent imaging of multiple animals.

WE-D-I-609-03

Improving the Quantitative Accuracy of a Dedicated Small Animal SPECT/CT Scanner

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Purpose: High-resolution radionuclide imaging is an important method for noninvasive assessments of small animal models of human disease. To improve the quantitative accuracy of small animal SPECT/CT, we have developed methods to calibrate the imaging geometry and energy response, and to perform attenuation correction. **Method and Materials:** All studies were performed using the X-SPECT (Gamma Medica, Inc.), which consists of a compact scintillation camera and microCT system on a common gantry. Attenuation correction was performed developing a method to convert CT image values into attenuation coefficients by imaging a calibration phantom containing materials having known linear attenuation coefficients, and was assessed by acquiring SPECT images of phantom containing an aqueous solution of iodine-125. The pinhole imaging geometry parameters were determined by scanning three point sources, and using a fitting algorithm to determine the values of the parameters. A pixel by pixel energy calibration was performed by acquiring data in list mode from flood phantoms**. Results:** CT calibration curves were obtained showing the correlation between CT image intensity and the linear attenuation coefficient for photons emitted by iodine-125 and technetium-99m. SPECT data reconstructed with attenuation correction improved uniformity, by eliminating the cupping artifact that otherwise decreases image intensity at the image center by 30%. The calibration for the imaging geometry resulted in a 10% change in image dimensions compared to images reconstructed using the nominal values for the

geometric parameters. The energy calibration corrected for photopeak changes that varied as a function of spatial position and radionuclide photon energy, and produced images with improved uniformity. **Conclusion:** We are able to improve the quality and quantitative accuracy of SPECT images by applying improved image reconstruction and list mode processing techniques. Conflict of Interest: Bruce Hasegawa receives research support from Gamma Medica. Brad Patt, Joshua Li, and Koji Iwata are Gamma Medica employees.

WE-D-I-609-04

Comparison Between PET And Bioluminescence Imaging For Quantitative Assessment Of Tumor Burden

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Purpose: A number of imaging modalities have been described for the study of rodent models of human biology and disease. Several of these modalities are based on traditional clinical imaging approaches, such as MRI, CT, PET/SPECT, and can often serve as methods for validating some of the newer modalities such as bioluminescence imaging (BLI), which has shown to be a highly sensitive tool for visualizing tumors, neoplastic development, metastatic spread and response to therapy. In this report, the ability of BLI to noninvasively quantitate the growth of orthotopic rat neuroblastomas was investigated. **Method and Materials:** Male nude (nu/nu) mice 7 - 8 weeks of age were used in this study (N=6). Orthotopic rat neuroblastomas derived from N2A neuroblastoma cells genetically engineered to stably express firefly luciferase ($N2A^{Luc}$) were implanted subcutaneously by injecting 100 µl NaCl (0.9%) containing $3x10^6$ viable cells in the left hind flank of the mice. Tumor burden was monitored over time by quantitation of photon emission and viable tumor volume using a cryogenically cooled CCD camera and positron emission tomography (PET), respectively. Animals were injected 200uCi of ^{18}FDG one hour before PET imaging. The viable tumor boundary was delineated on PET images using an in-house software at each time point and the tumor volume was then calculated. **Results:** A comparison between the BLI findings and the PET-defined tumor volume revealed a good correlation (R^2=0.8) between detected photons and viable tumor volume. **Conclusion:** Before small animal imaging as a means to assess tumor growth and response to therapy in orthotopic tumor models, animal survival was used as the primary therapeutic end point. The ability of imaging to follow temporal changes in tumor volume and response to treatment in an individual animal provides an accurate and rapid method for assessment of experimental therapeutics.

WE-D-I-609-05

Optical Imaging of Tumor Microvasculature in 3D

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Purpose: Great interest exists at present in determining methods to image and understand tumor micro-vasculature structure and how it can be perturbed by a variety of agents, including radiation and anti-angiogenic drug therapies. Present methods including micro MRI and micro CT can yield high spatial resolution, but limited contrast in micro-vasculature makes determining subtle 3D structure problematic. We have developed a non-destructive optical method for imaging tumor micro-vasculature which can yield significantly greater image resolution and micro-vasculature contrast than achievable with existing technique. **Method and Materials:** Murine tumor micro-vasculature staining was achieved by in-vivo tail vein injection of dark-dye solution. After several minutes the HTC116 (human colon cancer) tumor was removed, washed in saline solution and set in 1% agarose gel. Tumor tissue was then taken through a clearing process prior to optical imaging. Light from a diffuse white light source was caused to traverse through the tumor tissue and a projection image was acquired using focussing optics and a CCD camera. Quantitative images of microvasculature density were reconstructed from projections acquired at multiple angles. **Results:** Good optical transmission was achieved through significant tumor samples (e.g. 1x1x1cm). Excellent contrast was observed between microvasculature and surrounding tumor tissue. Very high resolution (5 micron) isotropic 3D reconstructions were achieved through large whole mount murine tumor sample. The method can provide quantitative maps of micro-vasculature density throughout the tumor sample. **Conclusion:** We present a novel technique for imaging 3D micro-vasculature in tumor and normal tissue with unprecedented image resolution and contrast. Quantitative analysis of microvascular density in whole mount (i.e. unsliced or undisturbed) large tumor specimens is possible. The technique has potential as a valuable new tool for the analysis of tumor microvasculature and the effects of vascular perturbing agents (e.g. anti-angiogenic drugs and radiation).

WE-D-I-609-06

Comparison Between Two Small Animal Imaging CT Devices Used for Quantifying Lung Damage in Mice in Vivo

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Purpose: Compare two x-ray computed tomographic approaches to non-invasively assess lung damage in mice: a commercially available micro-CT and a prototype flat panel CT (fpCT) system. **Method and Materials:** The micro-CT system requires respiratory gating, has a fixed tungsten anode x-ray tube, and a CCD camera. A technique of 81 mA•sec at 80 kVp (0.16Gy) was utilized. The fpCT system accommodates a breath hold method, has a conventional CT x-ray tube, and two CsI flat-panel detectors. A technique of 800 mA•sec at 70 kVp (0.032Gy) with 200 µL of IV contrast was used. In this pilot investigation a subset of ten C57Bl/6 mice were analyzed; these mice received either 3 U/kg of Bleomycin to induce lung damage or saline for the control group by intratracheal administration. Both groups were serially scanned with both devices at baseline, 10, 14, and 21 days. Lung volumes at each time point were calculated using Analyze 5.0 for both the micro-CT and fpCT image data sets. **Results:** Analysis of micro-CT images resulted in smaller lung volumes than fpCT, most likely due to the gating procedure. Although the micro-CT images exhibited more detail, the fpCT images had less noise and more tissue contrast within the lung regions, enabling easier detection of lung damage. The net decrease in measured lung volume due to damage accumulation over 21 days was 40 % from micro-CT and 37 % from fpCT with respect to the average baseline lung volumes. Control mice lung volumes were stable to within 20% for both CT systems. **Conclusion:** The use of IV contrast with the fpCT system more than compensated for the reduced spatial resolution in this study. These mice survived multiple CT sessions even though lung damage was quickly accumulating in some cases. Additional data will be presented representing the complete study (n=19 mice).

WE-D-I-609-07

Analysis of Growth Dynamics of Treated Murine Liver Metastases Using Volumetric Ultrasound Micro-Imaging

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Purpose: Two methods were compared for analyzing therapeutic responses in an experimental murine liver metastasis model using longitudinal high-frequency three-dimensional (3D) ultrasound imaging. **Method and Materials:** B16F1 mouse melanoma cells were injected into the mesenteric vein of C57BL/6 mice to produce liver metastases. Treated mice received doxorubicin every second day starting seven days post injection and continuing until day 17. Untreated mice received saline injections on the same schedule. Imaging began eight days post injection and was performed every one to two days until day 19. Three-dimensional images were acquired using a VisualSonics Vevo 660 ultrasound system with a 40 MHz transducer. Metastasis volumes were measured in 3D images by manual segmentation. Two growth curves were constructed for each metastasis by computing least-squares fits of an exponential function and a Gompertz function, which is an exponential with a time-varying rate parameter, to the volume data. **Results:** Eight untreated and 24 treated metastases were monitored. A significant ($p < 0.05$ in Wilcoxon rank-sum tests) difference in untreated and treated tumor volumes was observed as early as day 12. The growth of untreated metastases was described equally well by exponential (mean ± standard deviation of $r^2 = 0.963 \pm 0.045$) or Gompertz ($r^2 = 0.974 \pm 0.034$) functions. However, Gompertz functions modeled the growth of treated metastases more precisely ($r^2 = 0.985 \pm 0.024$) than exponential functions ($r^2 = 0.970 \pm 0.041$). The difference between exponential and Gompertz r^2 values for treated growth curves was significant ($p = 0.040$). **Conclusion:** High-frequency 3D ultrasound

imaging is sensitive to changes in murine liver metastasis growth rate produced by a chemotherapeutic agent, and may be capable of characterizing temporal variations in the growth rates of treated tumors. **Conflict of Interest:** VisualSonics has licensed 3D reconstruction, visualization, and segmentation software from our laboratory.

WE-D-I-609-08

Multimodality Small Animal Imaging: Registration of Functional EPR Images with MRI Anatomy

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Purpose: Electron paramagnetic resonance imaging (EPRI) is a spectroscopic imaging modality being developed for functional and molecular imaging in small animals, and has potential for ultimate translation to clinical imaging. By utilizing contrast agents ("spin probes") whose EPR spectra are modified by the local environment, it is possible to produce images which directly measure important physiologic quantities. In studies of tumor response to radiation-mediated gene therapy we have utilized EPR oxygen images, which provide 3D oxygen maps with resolution of ~1mm spatially and ~3 Torr in oxygen partial pressure. Like functional nuclear medicine images, EPR oxygen images do not depict anatomy directly. Analysis is facilitated by the ability to use an anatomic image as a "roadmap" for interpretation of the functional images. We have developed methods for registration of EPRI with MRI to allow anatomically-based analysis of these functional images. **Method and Materials:** EPRI is performed using locally developed spectroscopic imaging systems. MRI is performed on a 4.7T dedicated small animal system. Several registration techniques have been newly developed or adapted from clinical multimodality imaging. Fiducial markers visible in both EPRI and MRI can be attached to the animal or to the immobilization device. Simple point-to-point registration is possible using this method. Surface-based and intensity-based registration methods have also been applied. Customized immobilization devices are fabricated using a polymer dental impression material, analogous to foam cradles used in radiotherapy. **Results:** Both anatomically directed analysis of functional EPR images and analysis of serial changes in defined anatomical regions during a course of therapy are enabled by the use of customized immobilization and anatomic/functional image registration. **Conclusion:** Image registration is critical for accurate interpretation of multimodality anatomic/functional small animal imaging. Techniques analogous to those in clinical use can be used with success in this setting.

Imaging Symposium — Room 611

Image Science: DQE and Beyond

WE-D-I-611-01

The Science of Image Quality: Early Concepts, Maturing Ideas, and New Research Problems

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Our understanding of what determines image quality in medical imaging has evolved from the early radical ideas of Albert Rose in 1948 to modern task-dependent signal-detection theory. In between, many concepts such as the noise-equivalent quanta and detective quantum efficiency have moved from being novel approaches to mainstream metrics with international standards in both academic and industrial laboratories. This presentation will provide a brief historical description of how these concepts evolved and how they are used at present. While they have proved very useful, all Fourier-based metrics must be interpreted carefully when used to describe new digital technologies. Both the strengths and limitations of these methods will be summarized with an emphasis on some problems currently being investigated.

WE-D-I-611-03

Non-Fourier Concepts in Image Quality

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Medical images are acquired for the purpose of gathering information regarding the disease state of a patient. The quality of the image should be a measure of how a specified task may be performed given the resulting image. Image quality is task dependent; one imaging system may provide images that allow better task performance than another system's for one task, but worse for another task. Determining the quality of an imaging system involves specifying the task of interest, the range of objects that will be imaged, and the observer (human or machine reader) who will perform the task. In radiography it has become common to use Fourier measures to describe image quality through a combination of Fourier-based measures of system resolution and noise. The Line Spread Function, when Fourier transformed, yields the Modulation Transfer Function (MTF) as a measure of system resolution. Use of the MTF to describe a system's resolution is appropriate when the imaging system is shift-invariant, that is, the line spread function is independent of position. Image noise is described in the Fourier domain by the Noise Power Spectrum (NPS). We can use the NPS to describe the noise in an imaging system whenever the noise properties are stationary, meaning that the variance and correlations between fluctuations in different locations are not dependent on their absolute location. These Fourier measures of system resolution and noise are commonly combined to give an overall figure of merit known as the Detective Quantum Efficiency (DQE). The DQE describes the signal-to-noise transfer characteristics of an imaging system as long as those assumptions of shift-invariance and noise stationarity are valid. In digital systems the image of an object is affected by the location of the object with respect to the pixel grid. In other words, the detector pixels cause the system to be shift-variant. In this case the MTF does not describe the resolution properties completely. This is particularly the case for tomographic systems, where the point-response function is quite position-dependent. Moreover, in real imaging systems the noise properties will depend on position, most notably because real patients always have structure. So, the Fourier-domain noise concept of Noise Power Spectrum does not capture all the properties of noise for real imaging systems and tasks. In this talk we will consider a general treatment of the imaging system as a mapping of information from the patient to the data, without the assumptions inherent in Fourier analysis. We will discuss approaches to the characterization of system resolution and noise in terms of position-dependent parameters. Once such position-dependent imaging properties of a system are determined, we can use them to calculate measures of image quality that summarize the usefulness of the images for the performance of various visual tasks.

Joint Imaging/Therapy Symposium — Room 6C

Imaging for Therapy Assessment

WE-D-T-6C-01

Introduction

E Jackson*, UT M.D. Anderson Cancer Center, Houston, TX

WE-D-T-6C-02

Role of Imaging in Drug Response: Challenges and Opportunities

L Clarke*, National Cancer Institute, Bethesda, MD

Advances in biomedical imaging technology such as anatomical, functional and molecular imaging methods permit new protocols and informatics tools to be developed for measuring drug response. There is, however, an increasing need to harmonize methods for data collection and analysis to provide a greater acceptance of these methods by the clinical community, and in particular, the pharmaceutical industry community. Recently the NCI and the FDA have entered into a broad inter agency agreement, referred to as the Interagency Oncology Task Force (IOTF) to review how to accelerate the use of biomarkers for measurement of drug response. Biomedical imaging is an integral part of this IOTF. NCI is also reviewing its drug trial infrastructure, including web accessible methods to access trial data to enhance the development of informatics tools to measure drug response. http://iotftraining.nci.nih.gov/

NCI Cancer Imaging Program (CIP) therefore has an interest in challenging the cancer center, academic and industry communities to engage in research that may lead to harmonization of imaging protocols, related quality assurance methods and data analysis methods as required to measure drug response across different imaging platforms and clinical sites. NCI is actively engaged, for example, in providing web accessible reference image data sets collected from drug response investigations. These efforts include providing annotated data to permit more standardized methods for

measuring the performance of related informatics tools, such as change analysis. They are part of an overall development of a large data archive and web query systems referred to as caBIG. http://imaging.cancer.gov/programsandresources/InformationSystems http://cabig.nci.nih.gov/

This presentation will outline example scientific and NCI programmatic opportunities in this area. The intent of this presentation is to challenge investigators to consider this area of research.

Educational Objectives;
1. Understanding NCI Imaging Initiatives

WE-D-T-6C-03

Development of Image Software Tools for Radiation Therapy Assessment

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There has been extensive recent interest in the potential power of emerging imaging tools for early prediction of therapy effectiveness, both related to tumor control and normal tissue damage. These prognostic indicators are the results of combining improved imaging hardware, specialized scanning protocols, and advanced image processing and analysis paradigms.

In order to study and eventually use these tools routinely in the radiotherapy process, serious consideration needs to be given to the software environment necessary for proper data collection and analysis ties to individual patients' treatments. Imaging for therapy assessment (IAT) presents a multidimensional information environment, requiring data from different imaging modalities and acquisition methods, as well as handling temporal data series, combined over short (breathing, dynamic contrast) and long (temporal changes over weeks of treatment) time periods. The information needed for relating these data sets for analysis (non-rigid transformations, proper labeling of studies to measurement states) exceeds the capacities of existing DICOM standards. The extraction of analyzed information and relation to regional (radiation) dose should be multidimensional, and not restricted to voxel-specific regions.

Examples of imaging studies underway for therapy assessment will be presented. Software requirements will be demonstrated through an example system currently in use to support clinical trials at the University of Michigan. This system was designed around the unique needs of IAT, and is able to combine information from multiple sources (e.g., MRI, MRS, CT, PET, radiation dose) and time periods in an intuitive interface. This system has been used for studies of blood flow and volume, regional venous perfusion, vascular permeability, water diffusion, metabolite, and local contrast enhancement for high dose radiotherapy trials in the brain, lung, and liver to date.

Educational Objectives::
1. Understanding the unique needs related to imaging for assessment of radiation therapy.
2. Understanding the required tools beyond those found in a typical treatment planning system
3. Understanding a common ground needed for combining efforts of imaging physicists, radiation physicists, physicians and statisticians.
4. Understanding opportunities for novel paradigm and algorithm development

WE-D-T-6C-04

MRI and MR Spectroscopic Imaging of Cancer Therapy Assessment

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Purpose: To describe the use of Magnetic Resonance Spectroscopic Imaging in the assessment of treatment response for prostate cancer and brain tumor patients. **Method and Materials:** Specialized 3D MR spectroscopic imaging acquisition techniques were developed for both 1.5T and 3 T MR scanners. Novel analysis and display software was developed for the processing and interpreting the MR metabolic imaging data. These techniques were applied in brain tumor and prostate cancer cohorts prior to and following radiation and/or hormonal therapy. Changes in metabolite levels were calculated and correlated with treatment response measures. **Results:** The MR spectroscopic imaging techniques demonstrated the ability to reliably detect metabolite levels at both 1.5T and 3 T. Significant metabolite ratios differences were observed between normal and cancerous tissues with greater spatial resolution at 3T. Following both successful hormonal therapy and radiation treatment, significant reductions in choline levels were observed in prostate cancer patients. Similarly decreases in choline correlated with therapeutic response in brain tumor patients and increased choline significantly correlated with recurrent/residual tumor. **Conclusion:** These studies demonstrate the ability of MR spectroscopic imaging to detect metabolic differences between cancer and normal tissues in brain tumor and prostate cancer patients and the ability to detect metabolic changes following therapy.

Professional Symposium Room 618

Legal Corner - Law Suits, Discrimination, HIPAA

WE-D-P-618-01 - (no abstract submission)

Therapy Scientific Session Room 617

Dosimetry Instrumentation

WE-D-T-617-01

Characterization of a New 3D Dosimetric Material ''PRESAGE'' TM

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(1) Duke University Medical Center, Durham, NC, (2) Heuris Pharma LLC, Skillman, NJ

Purpose: A pressing goal of modern radiation dosimetry is the development of effective and convenient three-dimensional (3D) dosimetry systems that can measure and verify complex dose distributions. 3D dosimetry materials do exist but improvements would be valuable especially with regards to stability, uniformity, ease of handling and re-usability. In this work we investigate and characterize the dosimetric properties of a promising novel material PRESAGE™. **Method and Materials:** A series of experiments were conducted to investigate the dose response, linearity, stability, reproducibility and dose rate dependency of PRESAGE™. To facilitate efficient evaluation of a wide range of parameters the experiments were performed on small samples of PRESAGE™ contained in optical cuvettes (1cmx1cmx5cm). A laser scanning system was developed that enabled pre-and post irradiation scanning of the profile of optical-density with depth along the central path of individual cuvettes at 633 nm. Cuvettes were also scanned in a spectrophotometer to detect spectral absorption. **Results:** The PRESAGE™ was found to be robust in regards to handling and exposure to laboratory environment. Linear relationship of optical response with dose was observed (within 3%) in cuvettes that had been handled and exposed to lab environment for significant periods. Good stability of optical contrast was observed up to 13 days post irradiation and the optical response had little dependency (within 3%) on dose rate. The dose response is significantly less than that observed with polymer gel dosimeters but PRESAGE™ formulations with enhanced sensitivity (0.16Gy/cm) have not yet been fully characterized. **Conclusion:** These evaluations of small samples of PRESAGE™ indicate a dosimeter that is highly practical and with good dosimetric properties. Of particular importance is PRESAGE's robustness in terms of exposure to air and materials, high stability of response with time post irradiation, and its high optical clarity.

WE-D-T-617-02

The Dose Response of Radiochromic Gel Dosimeters: Dose Fractionation Effects

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Purpose: To investigate the magnitude of dose fractionation effects on the dose response of radiochromic Ferrous – Xylenol orange – Gelatin (FXG) and gelatin-free FX dosimeters. **Method and Materials:** The FXG gels contained distilled water, 50mM sulfuric acid, 0.3mM ferrous-ammonium-sulfate, 0.05mM xylenol orange (XO) from suppliers Sigma(X0127) and Aldrich(22785-4), and 4% by mass of gelatin. On preparation, the liquid

gel was poured into 1cm polymethymethacrylate cuvettes, sealed with Parafilm and refrigerated to 4°C. Samples were irradiated using a ^{60}Co unit to 0-5Gy. Thirty minutes after irradiation, optical transmissions through the samples were measured (referenced to 1cm water-filled cuvettes) at 589nm using a spectrophotometer (Hitachi-Perkin-Elmer-139). Samples were re-irradiated to the same doses, followed by optical transmission measurements. The procedure was repeated with gelatin-free FX aqueous solutions containing XO supplied by Sigma, Sigma-Aldrich(398187-5G) and Aldrich, respectively. Optical transmission measurements were made through 10cm pathlength cuvettes to detect smaller differences. **Results:** For the FXG gel made with Aldrich XO, a linear dose response was observed in the first fraction irradiation but only above a threshold dose of 0.5Gy. Use of reagent grade Sigma XO lowered the dose sensitivity and threshold dose value to 0.2Gy. For both FXG gels, the threshold dose was removed by pre-irradiation with the first radiation fraction or by storing the gels for two weeks in the dark at 4ºC. FX solutions exhibited a similar behaviour as FXG gels thus suggesting that gelatin *per se* is not responsible for the threshold dose effect. **Conclusion:** FXG gels exhibit dose fractionation effects which can potentially lead to inaccurate dosimetry for segmented radiotherapy. Manufacturing FXG dosimeters with reagent grade XO lowers the magnitude of the threshold dose. It appears that accelerated oxidation by a uniform pre-irradiation or by auto-oxidation (through storage of gels for a pre-determined time) is needed to eliminate the threshold dose effect.

WE-D-T-617-03

Characterization of a Novel Diamond Detector

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Purpose: Test a novel diamond detector performance and applicability for radiation dosimetry. Detector sensitivity, stability and dependence on bias voltage, dose rate, energy and hardening have been studied. **Method and Material:** Detector was irradiated in a mini-phantom. A modified electrometer and an external high power supply were used to collect the charge generated at the sensitive volume of the detector. Readings in the electrometer were collected by a computer via a hyperterminal connection at a rate of 10 values per second. Beam parameters SDD=100 cm, 10x10 cm^2 field size were used. Dose rate was varied by altering the SDD. **Results:** Optimal charge collection stability was observed after a short pre-irradiation and at +100 V bias. External bias voltages up to 225 V applied to the detector resulted in proportional charge collection rates. Signal is proportional to dose rate. No substantial variation in charge collection was observed when the detector was hardened to 10 kGy. **Conclusion:** The tested diamond detector has most of the characteristics needed for radiation dosimetry. Its performance is stable and the uncertainties in the charge collection will not affect the calculation of parameters in dosimetry. Therefore, this novel diamond detector is suitable for clinical use. **Conflict of Interest:** Research was supported in part by Standard Imaging Inc.

WE-D-T-617-04

Development of a New Fiber Optic Scintillator Dosimeter System

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Purpose: To develop a new fiber optic scintillator dosimeter system with high sensitivity and spatial resolution for absorbed dose measurement of low-energy x-ray emitting brachytherapy sources in water. **Method and Materials:** A novel fiber optic scintillator dosimeter system has been developed to obtain the dose distribution in three dimensions in real time around low-energy x-ray-emitting prostate brachytherapy seeds. A unique combination of small sensitive volume (0.5 mm diameter x 0.5 mm thick), novel scintillator geometry and low noise detector electronics allows unprecedented resolution in dose-mapping of brachytherapy sources. High sensitivity and wide dynamic range is achieved by proprietary detector technology and signal processing methods, allowing measurements of the very low dose rates at distances of up to several centimeters from a seed mounted in a water phantom. A simple USB interface connects the dosimeter to a host PC for data acquisition and analysis. **Results:** The detector has been mounted in a water phantom and the dose distributions around 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. The lower limit of practical dose-rate measurements for low-energy x-ray emitting sources is estimated to be 1mGy / h. **Conclusion:** The development of this new, high sensitivity, high-resolution fiber optic scintillator dosimeter, has allowed real-time characterization of the dose distribution around prostate brachytherapy seeds in water. Compared to the state-of-the-art TLD systems currently in use, this fiber-optic scintillator-based dosimeter system allows more rapid dose distribution measurements directly in liquid water instead of tissue-equivalent plastic. **Conflict of Interest:** This work supported by a NIST SBIR grant SB1341-03-W-0815

WE-D-T-617-05

Evaluation of the New Exradin A16 Micro-Chamber for the Purpose of Water Measurements of Small SRS Collimator by Comparison to Film Dosimetry and Monte-Carlo Calculations

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Purpose: Direct water measurements of small fields in general and small SRS collimators in specific have been a long known problem. The typical ion chambers, which are used with 3D water phantoms have a volume of about 0.125cc, which is not suitable for measuring small fields. The recently introduce Exradin A16 chamber, with a volume of 0.007cc was designed to overcome the problem by allowing accurate measurements of small fields in water. The purpose of this work is to validate the suitability of this chamber for small fields water measurements. **Method and Materials:** In order to evaluate the suitability of the A16, depth dose curves and a set of profiles were taken with this ionization chamber using SRS collimators ranging from 1cm to 4cm in diameter, in steps of 0.25cm increment. The scans were then compared with film dosimetry of the same collimators and Monte-Carlo simulations. The films used were the Kodak XDR extended range films in Perspex phantom, which were scanned and analyzed using the Vidar 16 scanner and the RIT software. The Monte-Carlo simulation was done using the BEAMnrc code. For the larger collimators (2.5cm and up) a set of water measurement were performed also using the standard Wellhoffer chambers (0.125cc) **Results:** The result showed excellent matching between all evaluations media (water measurements with the A16 and the standard chamber, film dosimetry and Monte-Carlo simulation). The only discrepancy was with deeper depths in the films, which was due to the phantom used. **Conclusion:** The A16 is suitable and should be used for small field water measurements.

WE-D-T-617-06

Development of a Sealed Water Calorimeter for Clinical Electron Beams

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Purpose: The purpose of this project is to develop a water calorimeter for use in clinical electron beams to directly determine absorbed dose to water. This work presents the design of the Electron Sealed Water (ESW) calorimeter, preliminary measurements and evaluation of correction factors. **Method and Materials:** The calorimeter contains a 30 x 30 x 20 cm^3 water phantom surrounded by a cooling system to allow for operation at 4^{o}C. Two thermistor probes measure the temperature change inside a glass vessel filled with high-purity nitrogen-saturated water. Correction factors for the glass perturbation were calculated using Monte-Carlo simulations. Corrections for thermal conduction were simulated using Femlab finite element modeling software. Resistance of the thermistor probes was measured using a lock-in amplifier and an AC bridge circuit. Measurements were done for 6, 9, 12, 16 and 20 MeV electron beams from a Varian Clinac 21EX with a 10 x 10 cm^2 applicator at 105.5 cm SSD with the thermistor probes positioned at d_{ref}. Irradiations of 667 MU were done at 1000 MU/min for an irradiation time of 40 s. Measurements were also taken with a PTW Roos ion chamber inside the calorimeter phantom. **Results:** The standard error on the mean temperature change for each energy was less than 0.2%. Reproducibility for measurements on separate occasions was 0.2%. When normalized to the 12 MeV measurements, values of k'_{R-50} for the Roos chamber calculated from calorimeter measurements for the 9, 16 and 20 MeV beams and agreed with TG-51 values within 0.7 %. **Conclusion:** Water calorimetry in electron beams has

previously been regarded as unfeasible as high dose gradients were thought to provoke unmanageable temperature gradients. Using the ESW calorimeter, we have shown for the first time that reproducible measurements can be performed in electron beams with energies as low as 6 MeV.

WE-D-T-617-07

Development of An Independent Audit Device for Remote Verification of 4D Radiotherapy

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Purpose: To develop a 4D quality assurance device for remote verification of dose delivery at institutions participating in NCI-sponsored clinical trials that require the use of respiratory motion mitigation techniques. **Method and Materials:** A plastic reciprocating platform was designed and constructed to simulate respiratory motion in two dimensions and to evaluate the reproducibility of 4D image acquisition and dose delivery. An anthropomorphic lung phantom was used with the platform to assess imaging characteristics, to provide CT data for radiotherapy treatment planning and for dosimetric evaluation. The lung phantom used radiochromic film in three major planes and TLD centered in the GTV. Static, simulated free-breathing, breath-hold, 4D phase-sorted and respiratory-gated CT image sets were acquired using the programmable moving platform. A volumetric comparison of internal phantom structures assessed imaging reproducibility. Conformal 6 MV photon treatment plans were created for free-breathing ITV and respiratory–gated techniques using Pinnacle. The reproducibility of the 4D irradiation techniques was analyzed through comparisons to calculated treatment planning dose data. Criteria for evaluation were derived from TG-53 with a range of 5%/3mm to 7%/7mm. **Results:** CT image analysis showed mean(SD) tumor volumes [cm^3] of 24.5(0.4), 23.1(1.6), 24.1(1.6) for static, 4D phase-sorted and free-breathing techniques, respectively. Initial evaluation of the ITV technique showed that the ratio of TLD/Pinnacle dose was 0.972. Axial film analysis with binary agreement maps showed ranges of 85.5% to 96.4% and 81.0% to 95.4% agreement within the 5%/3mm to 7%/7mm criteria range for gated and ITV techniques, respectively. Axial profile analyses through the tumor center indicated regions of disagreement between the measured dose data and calculated data within the 5% criterion. **Conclusion:** The 4D phantom QA system can be used as an independent audit device for dosimetric evaluation of 4D radiotherapy techniques.

Work supported by PHS grant CA10953 and CA81647 awarded by the NCI.

WE-D-T-617-08

Cone Beam Optical CT Scanner for 3D Dosimetry

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Purpose: To evaluate the performance of a cone beam optical CT scanner and to evaluate use of the scanner with a 3D solid radiochromic dosimeter. **Method and Materials:** The operating characteristics of a cone beam optical CT scanner were investigated using phantoms and solid dosimeters. The scanner acquires projection images (12 degree fan angle, 9 degree cone angle) during a single 360 degree rotation of a sample. 3D Images are reconstructed using Feldkamp backprojection with a Hamming filter. Background attenuation coefficients are removed by subtracting reference (pre-irradiation) images from data (post-irradiation) images prior to reconstruction. Reconstructed images have isotropic 2 mm, 1 mm, or 0.5 mm voxel dimensions in a 10 cm cube. Spatial resolution and image distortion were evaluated with a wire phantom and holes drilled in a solid dosimeter. Solid dosimeters were irradiated with a rectangular field and a complex Tomotherapy field. Profiles from scanned images were compared to profiles in calculated dose maps. **Results:** Reconstructed images of the geometry phantoms showed no spatial distortions. Artifacts are similar in appearance to sampling and beam hardening artifacts common in X-ray CT. Attenuation coefficients in neutral density liquids are linear with respect to the spectrophotometer readings. Line profiles through calculated and measured dosemaps show qualitative agreement. Scanning times varied from 3 to 9 minutes. Reconstruction times varied from 2 to 20 minutes. The total time to scan a dosimeter was less than 1 hour. Conclusion: The optical CT scanner and solid dosimeter form a promising 3D dosimetry tool. Geometric accuracy, spatial resolution and imaging times are within clinical requirements **Conflict of Interest:** This research is funded by Modus Medical Devices Inc. and Heuris Pharma LLC. The authors have a commercial interest in the scanner and/or the dosimeter.

WE-D-T-617-09

A Novel Approach to the Optimization of Beam Current Modulation for Proton Therapy Beam Using Passive Scattering

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Purpose: To develop an effective and efficient method for optimizing the beam current modulation (BCM) pattern in commissioning proton beams using passive scattering and range modulation wheels. This modulation pattern is essential in producing beams with properly weighted spread-out Bragg peaks for the desired depth-dose distribution. **Method and Materials:** The proton beam nozzle houses the spinning modulation wheel (600 rpm) and the various scattering components and translates the modulated beam current to a depth-dose distribution. This translation can be described, for a specific configuration of the nozzle, i.e., with a specific wheel position at a specific time, by a function C(x, t), defined as the dose produced at depth x and time t for a unit beam current at the time t. While the function C(x, t) is difficult to calculate theoretically due to the complex scattering paths in the nozzle and the phantom, it can be easily obtained by measuring the dose as a function of time and by a proper deconvolution taking into account the delays from the measuring circuit. With C(x, t) determined, one can calculate the depth dose distributions for any given BCM. Then the optimal BCM can be found, not by repeated measurements, as was often done before, but by numerical calculations. A window-based software has been developed to measure the time-dose functions and to perform numerical BCM optimizations. **Results:** The method was applied to optimize the BCM for a number of proton beams. The differences between the calculated and measured depth dose distributions are less than 1%, well within the clinical requirement. **Conclusion:** We have developed an effective and efficient method for optimizing the beam current modulation for proton therapy beams using passive scattering.

Therapy Scientific Session — Room 6E

IMRT Optimization

WE-D-T-6E-01

A New Lung IMRT Planning Algorithm with Dose Shaping Strategy to Compensate for Respiratory Motion

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Purpose: To develop a new lung IMRT planning algorithm that shapes dose distributions to the probability distribution of the tumor over the breathing cycle in order to compensate for respiratory motion, thereby enabling tumor dose escalation. **Method and Materials:** We implemented a new optimization algorithm on an in-house IMRT planning system on an Eclipse® workstation (Varian, Palo Alto). Our new dose shaping algorithm makes the dose of each voxel on the 3-D dataset proportional to its probability of being inside the tumor over the respiratory cycle. The maximum dose is set to be the prescription dose multiplied by the ratio of the volume encompassed by the extreme positions of the tumor to the tumor volume. We also implemented two other popular approaches: (1) an optimal margin method in which the margin is generated based on the extreme positions of the tumor; and (2) a convolution method that performs 4-D dose calculations using a modeled tumor motion probability density function. A simulated 4-D CT dataset, which was generated by superimposing the patient's respiratory motion pattern onto one's 3-D CT dataset, was used to evaluate the performance of these three approaches via DVH comparison for the inhale phase of the breathing. **Results:** Five-field 6MV beams were used for all plans delivering a total dose of 63Gy in 35 fractions. Comparing to the IMRT plan with optimal margin, the convolution method reduced the mean dose to the ipsilateral lung by 5% while maintaining the same tumor coverage. Compared to the convolution method, our dose shaping method achieved the same lung sparing, but is

much faster and has the extra ability to escalate tumor dose: 95% tumor received more than 72Gy. **Conclusion:** Dose shaping method is able to spare the healthy lung tissue, and has the capacity to further facilitate dose escalation.

WE-D-T-6E-02

A Clinical Planning Tool for Optimization of Intensity Modulated Radiotherapy Parameters

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Purpose: To develop a clinical tool that incorporates novel strategies to optimize all involved parameters in IMRT treatment planning: (a) the number of beams, (b) beam orientations, and (c) fluence maps. **Method and Materials:** An IMRT planning tool was developed in the MATLAB (The MathWorks, Natick, Ma.) environment with the capability of interfacing to a commercial treatment planning system. It consists of three components: image segmentation, parameter optimization, and isodose and dose-volume histogram (DVH) display. The parameter optimization tool starts with a large number of user input feasible beam orientations and sequentially eliminates beams. Beam elimination is terminated when unacceptable deterioration of the critical structure DVH is encountered. The algorithm uses the novel strategy of forcing the sequential dose distributions to imitate, as best as possible, the dose distribution with all beam orientations. This not only ensures a clinically acceptable final dose distribution but also greatly speeds up the computation time by pre-knowledge of the expected dose at every point in the patient body.
This process is illustrated in a typical prostate cancer IMRT plan with prescription doses to prostate and seminal vesicles expanded by 1cm, and more stringent than usual constraints to rectum, bladder, and femoral heads. **Results:** For the case illustrated, the parameter optimization tool sequentially reduced the number of selected beams from a user input 36 to 7 beams. Reducing the number of selected beams below 7 resulted in abrupt deterioration of the critical structure DVHs. In the tested cases, the resulting dose distributions are clinically excellent owing to the novel strategy of imitating the dose distribution with all beams. **Conclusions:** The clinical tool presented here serves an important purpose by promoting the extraction of the full benefit of IMRT by optimizing all involved parameters. It can interface with commercial treatment planning systems to enhance their functionality.

WE-D-T-6E-03

Development of a Fast Algorithm for Classifying Data Points as Inside Or Outside a Polygon

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Purpose: Adaptive IMRT with image guidance requires rapid computation of dose for frequent re-optimization. As patient geometry changes throughout treatment, millions of voxels must be continually associated with the various radiotherapy structures that are delineated for the patient. In beamlet dose models it is advantageous to identify only those voxels which can receive significant dose. Both of these tasks rely on a rapid point-in-polygon classification algorithm, which has not been improved since Siddon's work in the 1980s. We present a new algorithm that significantly outperforms the standard algorithm. **Method and Materials:** A point-in-polygon classification algorithm was developed. Current algorithms spend substantial computational time calculating cross products between polygon vertices and grid points to establish intersection points. We present a method where entire rows of dose points are classified together using a single ray. Further, we avoid computing cross products by translating the structure polygons so that rays are cast along the +X axis (assuming polygons lie in X-Y planes). Crossings are observed where vertices display a change in Y coordinate sign. This algorithm was compared to the Siddon algorithm, with our in-house treatment-planning system for both associating voxels with radiotherapy structures and targets and for voxel down sampling using stereographic projection. **Results:** Our new point-in-polygon technique shows considerable decrease in calculation times. 1.7 million voxels classified in 14 structure polygons produced a 100 fold decrease (2.1 vs. 213 s on a 3.6 GHz p4 PC) in computational time. Voxel down sampling using stereographic projection in the computation of 1,466 beamlets produced a 1.8 fold decrease (185.2 vs. 334.5 s) in computational time. **Conclusion:** Significant improvement in performance over the existing cross-product method for polygons has been observed with the new algorithm. However, parallel computation is still currently required to produce a typical IMRT treatment plan in less than one minute.

WE-D-T-6E-04

EUD Based Beam Orientation Selection

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Purpose: To develop a clinically sensible beam orientation ranking model with incorporation of dose-volume effects and to show its utility for IMRT beam placement. **Materials and methods**: Generally, a beamlet/beam is more preferable if it can deliver a higher dose to the target without exceeding the sensitive structure(s) tolerance. In previous geometry- or dose-based approach, the beamlets are treated independently and, to compute the maximally deliverable target dose, each beamlet is pushed to the maximum intensity without considering other beamlets. When volumetric-structures are involved, there are numerous dose distributions corresponding to the same dose-volume tolerance and the beamlets are no longer independent. We model a volumetric organ by using EUD and find the beam profile that delivers the maximum target dose without violating the EUD constraints using an iterative algorithm. Four clinical cases are planned with and without the guidance of the angular ranking information and the qualities of the two types of IMRT plans are compared. **Results**: An angular ranking model with consideration of volumetric effect has been developed. It is shown that the previously reported dose-based angular ranking represents a special case of the formalism proposed here. Application to four IMRT cases indicated that the proposed technique is capable of producing clinically sensible angular ranking. In all cases, we found that the IMRT plans obtained under the guidance of EUD-based angular ranking are significantly improved in comparison with that obtained using the conventional uniformly spaced beams. **Conclusion:** The EUD-based function is a general approach for angular ranking and allows us to identify the potentially good and bad angles for clinically complicated cases. The ranking can be used either as a guidance to facilitate the beam placement or as prior information to speed up the beam configuration optimization.

WE-D-T-6E-05

Geometrically Assisted Selection of Optimum Beams in IMRT Planning by Techniques of Computer Vision

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Purpose: To define optimum beam orientations in IMRT by geometric analysis of the PTV and OARs using techniques of computer vision. The method is particularly applicable to situations when one or more OARs are adjacent to the PTV and where non-coplanar beam orientations are employed, but can be used in cases requiring coplanar beams. The selected beam orientations are those that can most effectively yield desirable dose distributions in the PTV, sparing to a maximum extent adjacent OARs. **Method and Materials:** For each voxel of a PTV-OAR interface, Gaussian Invariant techniques are used to obtain the two orthogonal components of a vector that defines a tangent plane. A two-dimensional histogram of the number of voxels having specific values of those two vector components is formed. Clusters or peaks in the histogram correspond to dominant plane orientations in the interface. Considering the anatomy of a patient whose PTV and OARs have been projected on the surface of a hemisphere, each histogram cluster gives rise to an arc on that surface. Any beam oriented from a point in that arc towards the isocenter is then a possible optimum beam. At the present stage of development, the planner selects one or more optimum orientations for each OAR by using beam's-eye-view (BEV) tools. **Results:** Initial application of the method to clinical cases yields optimizations that are consistent with current clinical practice, with the geometrically assisted definition of optimal beams taking a small fraction of the time usually needed for that task. **Conclusion:** The work presented can be the basis of a nearly full automatic method of optimal beam orientation selection in which dominant arcs on the hemispheric surface are found by a self-organizing network and the subsequent BEV analyses are carried out automatically by a rule based system.

WE-D-T-6E-06

Implementation of a Fast Incremental Algorithm for Voxel Radiological Path Determination

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Purpose: Performing adaptive image-guided IMRT will require rapid computation of dose for frequent IMRT fluence map optimization (FMO). Patients should not have to tolerate waiting more than a few minutes for a new IMRT treatment plan. Most beamlet dose models in IMRT FMO expend considerable time performing voxel based ray-tracing computations. Improvements in voxel based ray-tracing algorithms have not been presented in the radiation therapy literature since the seminal work of Siddon in the 1980s. We present an algorithm that significantly outperforms the voxel ray-tracing algorithm of Siddon when applied to density scaled radiological path length calculations in patient voxel space for beamlet dose computation. **Method and Materials:** An incremental voxel ray tracing algorithm that simultaneously computes voxel indices and ray-voxel intersections was developed. The majority of the computational time required by the standard Siddon algorithm was found to be in the concatenation of the intersection parameters (α's) into a single unique set and the conversion of the calculations of the voxel indices from floating point to integer values. This algorithm was compared, as components of our in-house IMRT planning system, to the standard Siddon technique. The test case had 1.7 million total voxels on a 2.5 mm isotropic dose grid and the 1,466 beamlets in the IMRT plan intersected an average of ~15,000 voxels per beamlet. **Results:** Use of the new algorithm for the test case demonstrated a 2.7 fold increase in computational speed on average over the Siddon algorithm. **Conclusion:** The new algorithm provides a significant improvement in voxel ray-tracing performance over the standard Siddon algorithm. However, parallel computation is still currently required to perform the computation of a typical IMRT treatment planning rapidly enough for adaptive IMRT FMO.

WE-D-T-6E-07

Incorporating Clinical Outcome Data Into IMRT Inverse Planning

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Purpose: To develop a biologically more sensible yet clinically practical framework for IMRT planning by incorporation of existing clinical endpoint data. **Method and Materials:** To effectively integrate outcome data into inverse planning, two critical steps are (i) identifying the variable that characterizes the dose-volume status of an organ; and (ii) writing the objective function as a function of the variable with consideration of outcome data. The concept of effective volume is extended to the voxel domain for this purpose. For a dose-volume structure, the objective function depends not only the dose, but also its volumetric status. When compared with conventional quadratic function, the effect of the new scheme is to modulate the penalty distribution by applying more penalties on those high-dose voxels, and *vice versa*. The modulation is organ dependent and determined by the clinical outcome data. An iterative algorithm is used to optimize the system. The new formalism is applied to plan a head-and-neck case and a prostate case. The results are compared with that obtained using the quadratic objective function with DVH constraints. **Results:** The technique provides clinically sensible ranking of competing IMRT plans. For parotid glands, for example, it yields the same score when the glands are irradiated 15Gy to 67%, or 30Gy to 30%, or 45Gy to 24% of the volume since they lead to the same outcome. On the contrary, the quadratic function yields different rankings for the three scenarios. Comparison with conventional technique indicated that, for the same target coverage, critical structure sparing is substantially improved for both cases. **Conclusion:** A new penalty scheme, in which the voxels are penalized differentially according to clinical outcome data, is proposed. The sub-optimal performance of the current dose-based inverse planning can be substantially improved by considering outcome data.

WE-D-T-6E-08

Iterative Regularization of the IMRT Optimization Problem

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Purpose: To generate the optimal deliverable plan resulting from a beamlet-based IMRT optimization approach followed by conversion into machine parameters. This is achieved by utilizing iterative regularization to create smooth profiles. **Method and Materials:** Our iterative regularization scheme utilizes a quasi-Newton method with the identity matrix as initial Hessian estimate. The optimization process is terminated before jagged profiles occur, but it is run long enough to generate a dose distribution close to the optimal one. We discuss the one-to-one correspondence between our quasi-Newton method and a preconditioned conjugate gradient method, and use conjugate gradient theory to predict the behavior of our approach. **Results:** To verify our theoretical analysis, we study the performance of our method on a five beam prostate case with dose-volume objectives and bounds on the beamlet weights. The plan is optimized using ORBIT. For this case, the jaggedness of the beam profiles increase with iteration number while the objective value decreases rapidly in the first iterations. The objective value after conversion with 50 segments attains a minimum after 40-50 iterations, indicating that further optimization, apart from increasing the calculation time, deteriorates the plan quality. **Conclusion:** The optimization method considered has the appealing properties of a conjugate gradient method, with fast decrease in the objective function and smooth profiles during the first iterations. In addition, the quasi-Newton method is preferable when including constraints. By terminating the optimization after relatively few iterations, we generate smooth fluence profiles that, after conversion, outperform the plan obtained by converting the jagged optimal fluence profiles. Our opinion is that iterative regularization is faster and easier to perform than other regularization techniques, and more rigorous than filtering methods. Further refinement of the treatment plan would require direct optimization of the segments. **Conflict of Interest:** Authors are stockholders in RaySearch Laboratories.

WE-D-T-6E-09

Machine Learning for the Geometry/Intensity Relationship in IMRT

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Purpose: We present a feasibility study for breast IMRT showing that, given enough training examples of patient CT images and corresponding plans, machine learning algorithms can predict a good plan for a new patient's geometry directly, without explicit numerical optimization and dose calculation. **Method and Materials:** From an expert's clinical plans for 22 patients, the features determining the optimized intensities were identified. We applied four machine learning algorithms (nonlinear regression, support-vector machines, k-nearest-neighbors, and barycentric interpolation) to automatically discover the relationship between the beamlet intensities and the input features on CT images. This was learned on a beamlet-by-beamlet basis to decrease the input and output dimensionality. Results were evaluated by comparing the predicted intensity and dose distributions to those from the clinical plan (ground truth). **Results:** First, the plan for each patient was learned from all remaining patients' plans. The average beamlet error (averaged over all patients) for the best method (support-vector) was -0.16%, with an average absolute error of 2.07%. D95 and D05 (97.1% and 105.3%, respectively), and V95 (97.6%) values for the support-vector method differed insignificantly from the expert's plans at the 5% significance level. A second experiment using smaller training sets and larger testing sets yielded an average error of 0.22% and an average absolute error of 2.27%, respectively, indicating that a few well-selected training datasets are adequate to learn the relationships. Plans could be predicted in <10 seconds. **Conclusion:** While the breast IMRT problem is relatively simple, this work indicates that machine learning has potential to ease the computational burden of IMRT in more complex sites (e.g. prostate, head and neck), where reducing the time for optimization parameter adjustment would be clinically beneficial.

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Workshop Room 608
Digital Radiography QC Workshop

WE-D-W-608-01
DR QC Workshop
J Seibert*[1], L Goldman*[2], (1) UC Davis Medical Center, Sacramento, CA, (2) Hartford Hospital, Hartford, CT

Quality control (QC) of digital radiographic systems requires qualitative and quantitative assessment to determine readiness for clinical image acquisition. Vendors of computed and direct radiography will demonstrate, in a "hands-on" workshop, methods used for implementing QC testing, including a description of radiographic phantoms, testing procedures, analysis of phantom images, pass/fail criteria, and methods of documentation. Attendees will have an opportunity to see quality control procedures and analysis via direct demonstration on each vendor's QC workstation, and be able to interact with the vendor representative in small groups during the workshop. A technology review of each digital system including details of system specifications, unique imaging capabilities, and QC will be presented.
Participants: Agfa, Eastman Kodak, Fujifilm, General Electric, IDC, Konica

Educational Objectives:
1. Learn about digital radiography equipment quality control procedures
2. Understand phantom designs and what the phantoms are testing
3. Determine acquisition parameters used for QC testing
4. Analyze sample data for "hands-on" QC analysis
5. Discuss issues related to exposure index, image artifacts, and QC data tracking

Educational Symposium Room 611
Teaching Diagnostic Physics to Radiology Residents

WE-E-E-611-01
Introduction - Goals
C Kelsey*, Univ New Mexico, Albuquerque, NM

Purpose: To introduce the purpose and topics of the Continuing Education Symposium "Teaching of Physics to Radiology Residents" **Method and Materials:** The Symposium consists of discussions of A) What physics instruction is attempting to accomplish; B) Where we are now in this endeavor. C) How Physics teaching can be improved; D) How can we measure our success and E) to provide a list of resources and aids physics teaching. The discussions will be based on the premise that the purpose of every teaching program is to provide the Radiology resident with a solid physics foundation both to understand and utilize the technology in practice 25 years from now, and to pass the ABR examination. A look at current and previous physics teaching practices and results will put today's discussions in perspective. Like it or not, most residents will take the ABR examination in their first year. There is a fundamental core base of knowledge including signal to noise effects on images, biologic effects of radiation, sources of artifacts which must be included in any physics curriculum. Questions regarding the depth and breadth of the physics curriculum will be reexamined. The use of computer and web based instruction will be discussed. **Results:** The results of this symposium are designed to assist current instructors of physics to be aware of changes in the expectations of our customers **Conclusion:** There are many challenges and opportunities facing today's physics instructors. The teaching of Radiology Residents may be improved through a review of what is being taught both in breadth and depth of material and the use of web based resources.

WE-E-E-611-02
Where Are We?
E Ritenour*[1], W Hendee[2], P Heintz[3], (1) University of Minnesota Medical School, Minneapolis, MN, (2) Medical College of Wisconsin, Milwaukee, WI, (3) Univ New Mexico, Albuquerque, NM

A survey regarding the perceived quality of physics instruction of radiology residents was sent to all radiology programs in 2004. An identical survey was sent to program directors and chief residents. The Presidents of the American Association of Academic Chief Residents in Radiology and of the Association of Program Directors wrote cover letters to accompany the surveys, encouraging the expression of frank opinions in this anonymous survey. This presentation will present the results of the survey and will provide some opinions concerning the meaning of the results. Discussion will include information regarding some recent decisions by the American Board of Radiology as to changes in the grading of the physics exam for residents.

WE-E-E-611-03
What Should We Be Doing?
P Heintz*, Univ New Mexico, Albuquerque, NM

Purpose: To discuss what contents should be included in a Physics Class for the Diagnostic Radiology Resident as part of Continuing Education Symposium "Teaching of Physics to Radiology Residents" **Method and Materials:** The presentation will concentrate on what is needed in teaching physics to meet the needs of today's radiology residents. Emphasis will be given to the need for teaching clinical physics. The physics material should be presented with only the necessary equations and mathematics. Diagnostic residents are visual people. As such the physics taught should explain what they are viewing. It should be based on lots of images and examples. An emphasis should be made on general rules that they can use in their daily practice: i.e. inverse square law, 15% rule, and the number 4 rule. The physics material should address primarily what a radiologist is looking at and what they can modify to change the image appearance. It should address the concept of risk vs. benefit. The AAPM MPEP committee has created two syllabi for the resident's physics curriculum. The curricula will be discussed. Questions will be asked such as: Are they complete? What should we do with them etc? Who should use them? How do they relate to the ABR physics written exam? **Results:** The results of this talk should give the audience an idea of what should be included in a physics class for the diagnostic radiology residents. **Conclusion:** The breadth of physics technology in diagnostic radiology has grown tremendously in recent years. It is the challenge of the instructor to explain this technology to the resident in a meaningful matter. Shortened physics time and distracted students have increased the challenges of the physics instructor.

WE-E-E-611-04
How Should We Be Doing It?
J Seibert*, UC Davis Medical Center, Sacramento, CA

UC Davis physics education to residents involves an educational curriculum with didactic lectures offered over a contiguous 9 week period, one hour per day during the noontime hour during the months of May, June, and July (this is in lieu of the normal noon lecture, which is held in the early morning and/or late afternoon). Teaching faculty are convinced that day to day continuity aids greatly in the successful delivery and understanding of physics concepts. Physics lecture materials are produced on overhead projector transparencies, and are identical to the notes provided to the residents. Interactive writing on the transparencies allows appropriate emphasis of important information, and allows the residents to concentrate on the lecture instead of trying to take notes. Another benefit of the overhead projector is the ability to maintain reasonable luminance in the room, permitting eye contact with the residents and keeping them awake and alert. Further study (e.g., "homework") is achieved by consulting the physics textbook from which a majority of the lecture content is extracted. Additionally, sample question and answer sets give the residents a feel for what is to be expected in terms of written examinations. Interactive, animated computer presentations are under development to aid in describing more difficult concepts, and eventually, migration to all computerized materials is planned. Finally, the residents attend a concentrated, 4 day summer physics review course taught by UC Davis faculty prior to the board exams.

Educational Objectives:
1. Illustrate the methods of physics teaching to residents at UC Davis Dept of Radiology
2. Describe teaching curriculum, time commitment, schedule for the residents

WE-E-E-611-05

The ABR Examination in Physics for Diagnostic Radiologists

D Bednarek*, University at Buffalo (SUNY), Buffalo, NY

The written certification examination in Diagnostic Radiology for radiologists consists of both a physics and a clinical test. The physics test is created by a committee composed of diagnostic radiologists and of practicing medical physicists who are content experts specializing in diagnostic radiology. There is input and review by officers and trustees of the ABR before and after the exam is administered. The test is composed of a predetermined number of used and unused question items and a predetermined number of items in the three general content areas of diagnostic radiology, nuclear medicine and radiobiology. All items are randomized on the final exam. The process of new item development begins about 18 months before exam administration, while the exam assembly meeting occurs about 10 months before the test date. Throughout the process, the committee is conscious of the need for the subject material to be current and relevant to the practice of clinical radiology. Every attempt is made to ensure the accuracy and clarity of the question items and that all distractors (incorrect choices) are plausible but clearly incorrect. Items are reviewed and revised as needed at each stage of the process. Following the assembly meeting, the ABR staff edits the items and prepares them for the test. The committee chair reviews all edits to ensure that item content and accuracy have not been altered. The staff then formats the exam and prepares proofs, which are again reviewed by the chair before it is sent to the printer. Following the exam, the statistical performance of each question is analyzed by the ABR psychometrician for difficulty and discrimination (point-biserial correlation) to flag potential problem items and any such items are reviewed for possible ambiguity or inaccuracy of the key. Production of each test is a long and meticulous process with every effort expended to ensure a fair and meaningful certification examination.

Educational Objectives:
1. To describe the process used in assembling the physics examination
2. To provide an overview of the content areas covered on the exam.
3. To review some of the changes that have been implemented by the ABR over the past several years

WE-E-E-611-06

Resources—Handouts

R Massoth*, Medical X-Ray Center, PC, Sioux Falls, SD

Purpose: To present resources available to Medical Physicists who teach Diagnostic Radiological Physics to Radiology Residents. **Method and Materials:** Web and published materials are listed. Links to web sites and web-published documents are included. **Results:** There are many on-line and printed Educator's Resources that are useful to a Medical Physicist in teaching Diagnostic Radiological Physics to Radiology Residents and Fellows. This handout describes some of the printed resources and provides URLs to on-line resources. Printed resources include AAPM Report #64 "A Guide to the Teaching of Clinical Radiological Physics to Residents in Diagnostic and Therapeutic Radiology". On-line resources include the resources on the AAPM web site, the web sites of other professional organizations, and the work-in-progress of AAPM Task Group #115. **Conclusion:** Improved Educator's resources for Diagnostic Radiological Physics instruction of Radiology Residents are available and will continue to be expanded.

WE-E-E-611-07

Summary

C Kelsey*, Univ New Mexico, Albuquerque, NM

WE-E-E-611-08

Panel Discussion

Panelist: P Heintz*[1], C Kelsey*[1], D Bednarek*[2], J Seibert*[3], M Rzeszotarski*[4], (1) Univ New Mexico, Albuquerque, NM, (2) SUNY Buffalo School of Medicine, Buffalo, NY, (3) UC Davis Medical Center, Sacramento, CA, (4) MetroHealth Medical Center, Chesterland, OH

Imaging Symposium Room 609

Image Perception

WE-E-I-609-01

Advances In Perception & Visualization

E Krupinski**[1], E Samei**[2], M Eckstein**[3], (1) Univ Arizona, Tucson, AZ, (2) Duke Univ, Durham, NC, (3) UC Santa Barbara, Santa Barbara, CA

Perceptual & Cognitive Mechanisms in the Interpretation of Medical Images – E. Krupinski
Optimizing Image Quality for Softcopy Reading - E. Samei
Modeling the human visual system for medical image interpretation – M. Eckstein

This symposium brings together scientists involved in unraveling the mechanisms involved in medical image perception, both from the perspective of understanding the human observer's perceptual and cognitive processes and understanding how the image and its display environment impact the observer. The symposium will begin with a discussion of why image perception is important and its role in the evaluation of image visualization and analysis tools such as computer-aided detection schemes. This will be followed by a discussion of the role of image quality in medical image perception and how various image quality parameters can impede detection and diagnosis of medical abnormalities. The third talk will describe some of the main approaches being used to model the human visual system as tools to better understand the diagnostic processes and predict how certain imaging conditions affect performance.

Educational Objectives:
1. Understand the importance of studying perceptual & cognitive mechanisms in the interpretation of medical images.
2. Understand the importance of optimizing image quality (from acquisition to display) in terms of interpretation and diagnostic accuracy.
3. Understand the role of methods used to model the human visual system as a means to better predict observer performance in medical image interpretation.

Joint Imaging/Therapy Scientific Session Room 6C

4D Modeling and Margin Assessment II

WE-E-J-6C-01

TOMAS, a Tool for Organ Motion AnalysiS

K Raj, P Guo*, T Raidy, M Oldham, Duke University Medical Center, Durham, NC

Purpose: On line cone-beam x-ray CT is a promising technique for image-guided-radiation-therapy (IGRT) by virtue of its ability to provide soft tissue contrast in 3D. IGRT enables correction for inter-fraction set-up error and organ motion, which can improve accuracy and opens potential for using smaller set-up margins. The key to IGRT margin determination lies in understanding intra-fraction organ motion, representing a paradigm shift from conventional treatments, where inter-fraction motion dominates. We present a technique and software tool to study intra-fraction motion, and present preliminary applications to cervix and prostate. **Method and Materials:** Single shot fast spin echo (SSFSE) MR sagittal images were acquired every 2 seconds at several slice locations through the target volume in several patients. Images were acquired over a period of twenty minutes, corresponding to a typical treatment fraction. Images were analyzed in a motion analysis software tool developed in Matlab. Special functions were developed to quantify aspects of target motion, including rigid body translations, drift, deformation, and rotation. Explicit functionality was also developed to analyze frequency aspects of intra-fraction motion. **Results:** Significant inter-patient variability of organ motion has been observed over time periods consistent with typical daily treatment time. In a cervix case a general drifting and rotation of the target position was observed (15 degrees), correlating with bladder filling. This was not observed in other cases. Observations of prostate motion suggest that the prostate maintains a relatively stable mean position and has only transitory discursions of up to 1cm related to rectal gas. **Conclusion:** Preliminary investigations of cervix and prostate target motion indicate that

characterization of intra-fraction motion is an important pre-requisite for determining optimal margins in IGRT treatments. A tool incorporating analysis of the frequency of motion will be presented to translate characterized motion into meaningful tumor margins.

WE-E-J-6C-02

Internal Fiducial Markers Can Assist Dose Escalation in Treatment of Prostate Cancer: Results of Organ Motion Simulations

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Purpose: We simulated effects of full (no repositioning) and reduced (using fiducial markers and on-line repositioning following EPI) uncertainties on dose distributions in PTV, prostate, and organs at risk – bladder and rectum; and evaluated limits for dose escalation if on-line repositioning is implemented and tight PTV margins are applied. **Method and Materials**: Three patients' anatomies, with large (68cc), medium (55cc) and small (40cc) prostate volumes were used. PTV margins of 2, 4, 6, 9 and 12mm were tested for a conventional 70Gy/35fr, and dose escalated schedules of 74Gy/37fr and 78Gy/39fr. Setup and organ motion uncertainties were modeled in a stochastic manner to generate a dose population histogram. The outcome of each treatment was then scored based on dose distributions in organs. These have been summarized as equivalent uniform doses (EUD) calculated on survival basis for prostate and effective doses from reduced dose-volume histograms for bladder and rectum. We deemed dose escalation acceptable as long as the currently observed complication rate was not exceeded. To verify validity of obtained margin prescription, 20 patients were studied with the above simulation methods with acceptable margins only. **Results**: With reduced positioning uncertainties using fiducials, the dose can be escalated to 78 Gy with a reduced PTV margin of 4mm without compromising tumor control probability. Even if large PTV margins (12mm) were applied and dose was escalated to 78Gy, bladder doses did not exceed tolerance levels. The rectal complication probability is comparable to the currently observed rates or even less if rectal bleeding is proven to show strong volume dependence (parallel model) even treating to 78Gy with 4mm margin. The additional 20 patients studied provided similar results. **Conclusion**: educed positioning uncertainties using fiducial markers allow us to reduce PTV margin to 4mm and escalate dose to 78Gy with similar or lower rectal toxicity rates.

WE-E-J-6C-03

A Method for Modeling Individual Patient Geometric Variation: Implementation and Evaluation

M Söhn*[1, 2], M Birkner[1], D Yan[2], M Alber[1], (1) Uniklinik für Radioonkologie, Tübingen, Germany, (2) William Beaumont Hospital, Royal Oak, MI

Purpose: We present and evaluate the method of *Principal Component Analysis* for modeling individual organ motion/deformation. This method provides the most important factors to characterize deformable organ motion, therefore assists adaptive radiotherapy planning. **Method and Materials:** Input are N organ shape samples, described by the positions of a set of corresponding surface points. The covariance matrix of displacement vectors is determined and diagonalized.

Each eigenvector defines a 3D-vectorfield of correlated displacements for the surface points, a so-called *eigenmode of deformation*.

Each eigenvalue gives the variance of the shape samples in direction of the corresponding eigenmode, thereby providing an importance ranking for the eigenmodes with respect to the displacement direction and magnitude.

Weighted sums of eigenmodes can be used to represent organ displacements/deformations. We evaluated the ability of eigenmodes to represent the measured samples by calculating the residual errors for the organ surface points, using a varying number of eigenmodes.

The method was applied to four datasets of prostate/bladder/rectum with N=15-18 CTs to assess interfractional geometric variation. Typically a few thousand surface points were used in the analysis. **Results:** The spectrum of eigenvalues is clearly dominated by only few values. This indicates that the geometric variability of the input samples of prostate/bladder/rectum shapes is governed by only a few patient specific 'deformation modes', quantitatively given by the corresponding eigenvectors.

The distribution of residual errors shows convergence with the number of eigenmodes used to represent the organ shapes. Using 4 dominating modes, the range of average residual errors is 1.3-2.0mm (prostate), 1.4-1.9mm (rectum) and 1.5-1.9mm (bladder) for the four patients. **Conclusion:** Individual geometric variation information taken from multiple imaging data can be described accuratuly by few dominating eigenmodes. This approach provides an efficient statistical model to characterize individual organ deformation, which quantitatively takes into account correlated motion of adjacent organ structures.

WE-E-J-6C-04

The Effect of Heterogeneous and Nonlinear Material Properties On Organ Deformation

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Purpose: The purpose of this research is to investigate the effect of intra-organ heterogeneous material properties on finite element model (FEM)-based deformable image registration. **Method and Materials:** Heterogeneities were included in the organ of interest, the liver for this initial study, in two ways: 1) by randomly distributing spheres of varying size (diameter: 0.5 – 1.5 cm) and number (19 – 79) throughout the liver and 2) by creating a single sub-volume of varying volume ratio (23 – 92%) by contracting the liver contour by varying amounts. A large number of simulation parameters were investigated, including Poisson's ratio (ν = 0.2 – 0.499), elastic modulus (E = 1 – 100 kPa), and hyperelastic properties (0.1 – 660% variations corresponding to 1 – 100 kPa) for varying volume ratios (3 – 92%) of the heterogeneous volume. The Taguchi method was used to investigate the contribution of each parameter to the average difference between the deformations of heterogeneous liver and those of the reference homogeneous liver. **Results:** The contributions of Poisson's ratio of the liver and heterogeneous volume sharply decreased and exponentially increased, respectively, as a function of the volume ratio of heterogeneous volume. The maximum contribution (20 – 51%) of the elastic modulus of heterogeneous volume was exhibited at the volume ratio of 54 to 67%. The result also indicates that the maximum average differences and 3-σ differences ranged from 1.2 to 2.4 mm (percent contribution: 28 – 55%) and 1.75 to 4.2 mm (percent contribution: 42 – 97%), respectively. **Conclusion:** This study indicates that the variations of the deformation by the material uncertainties are not negligible, but this parametric approach can be applied to extract the quantitative effects of the significant material parameters on the deformation of a heterogeneous liver having various material uncertainties. **Conflict of Interest:** Research supported in part by a grant from Varian Medical Systems

WE-E-J-6C-05

Variability of Four Dimensional CT Patient Models

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Purpose: Several studies address the use of 4D CT to increase the geometrical accuracy of radiotherapy for lung cancer patients. A single 4D CT scan, however, gives a 'snapshot' movie loop of the patient's respiratory motion. In this study, we investigated the variability of respiratory motion over the course of radiotherapy using repeated 4D cone beam CT (4DCBCT) scans. **Method and Materials:** 4DCBCT scans of 10 lung cancer patients were acquired on the linac just prior to irradiation for 7-13 fractions. The diaphragm motion, extracted automatically from the projection images, was analyzed in terms of period and phase-histogram (relative time spend in [exhale, exhale-to-inhale, inhale and inhale-to-exhale]). Tumor motion was determined by registering a region of interest from the planning CT to each phase of the 4DCBCT. **Results:** The average breathing period ranged from 2.1 s to 5.6 s for different patients, with an inter- and intra-fraction variation of 0.8 s SD. The average phase histogram was [0.3 0.23 0.2 0.27] with little variation between fractions and patients, i.e., patients generally spend more time at exhale than inhale. The mean (over all patients) intra-fraction variation (SD) of the average tumor position relative to the bony anatomy was 1.6 mm LR, 2.7 mm SI and 2.3 mm AP, reflecting baseline breathing variation. The peak-to-peak tumor motion ranged from 0.4 to 2.0 cm, with an inter-fraction variability of 16% (1SD). **Conclusion:** Substantial variation in respiratory frequency, mean tumor position and peak-to-peak amplitude was found. These uncertainties can be taken into account by adapting the CTV-to-PTV margin accordingly. 4D-patient models should be regularly updated, e.g., by

acquiring 4DCBCT prior to treatment, for safe implementation of precision 4D radiotherapy techniques like gating and tracking. **Conflict of Interest:** This research was sponsored by Elekta Oncology Systems Ltd.

WE-E-J-6C-06

Proton Treatment Planning for Mobile Lung Tumors

Y Kang*, X Zhang, H Wang, J Chang, Z Liao, R Komaki, J Cox, R Mohan, I Rosen, K Prado, P Balter, H Liu, L Dong, UT M D Anderson Cancer Center, Houston, TX

Purpose: Traditional treatment planning methods may lead to lung proton treatment plans in which the apparent and actual dose distributions may be significantly different due to respiratory motion. We are developing strategies for designing compensator-based 3D proton treatment plans using 4D CTs (composed of 3D CTs at a sequence of respiratory phases) for mobile lung tumors and assessing the validity of these strategies using 4D dose computation methods. **Method and Materials:** 4D CTs for a population of lung cancer patients were used to obtain tumor targets and critical structures. The internal target volume (ITV) was the composite of target volumes on the 4D CT. For each patient, we evaluated four compensator design and planning strategies based on (1) the average CT obtained by averaging all phases of the 4D CT; (2) free breathing CT; (3) maximum intensity projection (MIP) CT; and (4) the average CT with the CT numbers inside the tumor volume replaced by the corresponding MIP CT numbers. For each strategy, the resulting apparent dose distribution was compared with the corresponding 4D dose distribution computed by deforming dose distributions of each phase to the reference phase and summing. **Results:** The composite 4D dose coverage of the target was significantly superior for method (4) while normal tissue doses were slightly higher though well below the limits. A seemingly conservative compensator design using MIP for the entire image, not just the target volume (Method 3), resulted in poor proximal target coverage due to over-estimation of the densities of intervening tissues. **Conclusion:** 3D proton plans based on the CT obtained by averaging the 3D CTs comprising the 4D CT, and with the CT numbers in the tumor volume replaced by the corresponding MIP CT numbers, is an effective approach to achieve good tumor coverage and acceptable normal tissue sparing.

WE-E-J-6C-07

4DCT Proton Treatment Planning for Lung Tumors

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Purpose: We investigated the use of 4DCT data for proton radiotherapy of lung cancer patients. **Method and Materials:** We used 4DCT scans at inhale, exhale and mid-exhale as well as a free-breathing scan for four typical lung cancer patient geometries. Separate proton treatment plans were designed covering the CTV in the free-breathing CT-scan (plan:*FB*) and the mid-exhale phase (plan:*MH*). A uniform margin, of half the peak-to-peak breathing amplitude was applied to apertures and range compensators of both plans to account for effects of breathing motion on the dose distribution. A third plan was designed using time-resolved knowledge of radiological path lengths to the tumor for all breathing phases (plan:*4D*). Per patient, all three 4DCT-scans were used to evaluate tumor coverage. **Results:** Plan:*FB* covered the CTV in all breathing phases for 2 patients but severe underdosage occurred in 4/6 remaining scans, down to an equivalent uniform dose of 22.2 Gy (prescribed dose: 72 Gy). Plan:*MH* showed mild underdosage in only one scan while plan:*4D* guaranteed CTV coverage in all breathing phases. The average mean lung dose, evaluated using the free-breathing CT-scan was 100%, 104% and 93% for plan:*FB*, *MH* and *4D*, respectively, normalized to plan:*FB*. For the lung volume receiving at least 20 Gy these values are 100%, 102% and 91%, respectively. **Conclusion:** Using a "snap-shot" free-breathing CT-scan can lead to geometrical misses and a severe reduction in target dose coverage for proton radiotherapy of lung cancer. Using the mid-exhale phase of a 4DCT-scan plus a margin of half the peak-to-peak breathing amplitude greatly improves tumor coverage at a small additional cost in dose to the lungs. We developed a treatment planning method based on 4DCT data that ensures target dose coverage under respiratory motion while still minimizing dose to the lungs.

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Joint Imaging/Therapy Symposium Room 6B

Advances in Image-Guided Interventions

WE-E-J-6B-02

Image-Guided Minimally Invasive Robotic Surgery

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Image-guided surgery allows surgeons to specifically target diseased tissue while sparing healthy tissue, reducing morbidity and improving patient outcomes. Minimally invasive surgical techniques deliver specific intervention without the morbidity associated with large open incisions. Image-guidance technology has the potential to provide significant benefits for minimally invasive surgery, where surgeons must usually cope with difficult access and reduced visualization. A new generation of minimally invasive surgery has emerged that uses a robot to hold surgical tools during laparoscopy or thoracoscopy, under direct control by the surgeon. Surgical robots offer an excellent platform upon which to fuse the benefits of image-guided and minimally invasive surgery. The da Vinci surgical robot system has a high-fidelity video display, a stereo endoscope, and sensors to track the position of each surgical instrument and the endoscope, offering a potentially ready-made stream of data for registration and tracking.

The proposed project involved an academic/industry collaboration to give da Vinci the fundamentally new capability of steering to a specific point in the patient's frame of reference. Using the traditional da Vinci control paradigm, the robot simply follows the surgeon's relative motions and has no concept of the patient's frame of reference. With the new ability to navigate through the patient's frame of reference as described by preoperative imagery data sets registered to the patient during surgery, da Vinci will enable surgeons to more accurately perform targeted tasks such as biopsy, tumor ablation, resection planning, and gene therapy in a minimally invasive manner. The project used liver surgery as a motivating application. This work addressed three feasibility milestones: Establishing communication between the surgical robot and existing image-guidance software, establishing robot tracking error under 2 mm, and establishing surface registration errors under 5 mm.

WE-E-J-6B-03

Endoscopic Laser Projection for Image-Guided Surgery

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Purpose: The goal of this work is development of an endoscopic system for three-dimensional localization of tissue surfaces during image-guided surgery. The system has the potential to track tissue movement in real time and to measure the shape of organ surfaces within the endoscopes' fields of view via localization of thousands of surface points. The system is intended to provide real-time localization of surface points as a means to guide coregistration with preoperative anatomic image sets and to provide the constraints required by deformable tissue models. **Method and Materials:** A benchtop prototype of the system consisting of a pair of conventional endoscopes, a computer-controlled laser scanner, a high-speed CCD camera, and a commercial optical tracking system has been constructed in Creare's laboratory. Calibration of the prototype has been performed by verifying the accuracy of the optical tracking system used to measure the position of the endoscopes, measuring the repeatability of the laser scanner when projecting the laser through an endoscope, characterization of the distortion present in the endoscope optics, and the measurement of the maximum usable field-of-view. The accuracy of the system has been determined based on the difference between three-dimensional coordinates measured by our system with those measured by the commercial optical tracking system. **Results:** The repeatability of the system to consistently localize a fixed point was determined by measuring the location of 25 points while maintaining fixed positions of the endoscopes and laser mirrors. The mean three-dimensional repeatability of the localizations was 0.08 mm with a standard deviation of 0.05 mm. The accuracy of the system was ascertained relative to measurements made with the optical tracking system and a standard six LED probe, known to have an accuracy on the order of 0.1 mm. Using a planar test phantom with machined semicircular holes, the projecting endoscope laser was steered to the center of each hole, and the position of

the illuminated spot determined using the system. The position of each hole was also measured with the six LED probe, and the resulting three-dimensional error found to be 1.9 mm with a standard deviation of 0.3 mm. The system can localize approximately 400 points per second. **Conclusion:** The use of a scanning laser endoscope has the potential to provide cost-effective, real-time localization of any point within the surgical field that can be simultaneously observed by two endoscopes. The initial results of our work show that points can be localized accurately and rapidly.

Educational Objectives:
1. Calibration techniques for endoscopic laser projection.
2. Discussion of endoscopic localization as a means of assisting image-guided surgery.

WE-E-J-6B-04

Guided Radiation Therapy: Organ Motion Tracking with Implanted AC Electromagnetic Transponders

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The Calypso® 4D Localization System (Calypso Medical, Seattle, WA) is an investigational device using AC electromagnetic fields to identify a radiation therapy treatment target with very small (1.8mm x 8.0 mm) implanted radiofrequency resonant circuits in or near the tumor site (Beacon® transponders) without adding ionizing radiation. The Calypso System enables accurate treatment setup and real-time monitoring of the target with an objective and simple user interface. This new localization approach in radiation therapy is expected to be a very efficient and accurate method for real-time radiation therapy setup and monitoring of the treatment target site.

Technical and clinical evaluations have been performed with regard to system accuracy and monitoring target motion. Early phantom investigations result in sub-millimeter precision measured at 8 cm from the electromagnetic array ($\sigma x =$ 0.006mm, $\sigma y =$ 0.01 mm , $\sigma z =$ 0.006mm) and at 27 cm from the electromagnetic array ($\sigma x =$ 0.27 mm, $\sigma y =$ 0.36 mm , $\sigma z =$ 0.48 mm). Measurements were essentially unchanged during a 20 second sampling period. The average measured target position varied less than 0.01 mm at 8 cm and less than 0.15mm at 27 cm.

Twenty patients were implanted with Beacon transponders to study implant stability and biocompatibility. A subset of the 20 patients were localized with the Calypso System and monitored over an eight minute period in the radiation therapy treatment room. Natural prostate motion was demonstrated and ranged from few millimeters of motion from the setup position to a shift from setup of > 1cm. The system has been designed for body wide localization and monitoring applications. Technical and clinical studies are underway to assess the application of AC electromagnetic tracking of organ motion in the prostate and other sites in the body. Anticipated clinical applications include real-time radiation therapy treatment setup and tracking for prostate, lung, head and neck, partial breast, liver and pancreatic tumor sites.

Educational Objectives:
1. Explore clinical application for use of AC electromagnetics for guiding radiation therapy setup and monitoring.
2. Review technical accuracy and precision of AC electromagnetic system for radiation therapy.

Author is an employee of Calypso Medical Technologies.

WE-E-J-6B-05

New Applications and Continuing Challenges in Image-Guided Therapy

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Image guided therapy is based on the concept that knowledge of the location and orientation of a therapeutic process will allow for more specific therapy. That is, more of the therapeutic process can be applied directly to the volume of interest with reduced exposure of normal tissue to that process. This is true whether one considers surgery, ablation, radiation, gene therapy, chemo- therapy or implantation as you therapeutic process. Each application requires a multi-dimensional assessment of location, orientation, temporal and functional constraints so that the proper techniques can be developed, tested and validated. It is the latter that represents the greatest ongoing challenge.

Therapy Continuing Education Course Room 618

CE: Site Specific IMRT Planning - III

WE-E-T-618-01

IMRT in Gynecologic Malignancies

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Intensity modulated radiation therapy (IMRT) is increasingly used for the treatment of gynecologic malignancies. In a survey conducted in 2004, we 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 region 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 the PTV and surrounding normal tissues 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). Acceptability criteria for the bladder, rectum and pelvic bone marrow will also be discussed. At our institution, quality assurance is performed using an independent monitor unit verification (MUV) program and patient-specific measurements. In gynecologic patients, an acceptable disparity between the treatment planning system and MUV calculation is 0.2% +/- 1.1%. An additional consideration is that the relatively large treatment fields in whole pelvic gynecologic IMRT necessitate splitting individual fields to accommodate the limitations of the MLC carriage motion. The dosimetry of these split fields and measurements of the junction region 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 understand the IMRT quality assurance issues for this disease site

WE-E-T-618-02

IMRT for Prostate Cancer

R Price*, Fox Chase Cancer Center, Philadelphia, PA

While arguably the most mature site for IMRT use, prostate treatments still require 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 this results in additional dose to surrounding normal structures. We attempt to reduce the uncertainty by employing active localization using BAT ultrasound and currently use a 8mm PTV in all directions except posteriorly where a 5mm margin is typical. Patients

being irradiated in the post-prostatectomy setting undergo localization via an in-room CT scanner. These methods allow for minimal expansion of the PTV by moving the prostate or prostate bed into the appropriate dose region on a daily basis. All patients are simulated and treated supine without a thermoplastic immobilizer to facilitate the use of ultrasound and to minimize respiratory related prostatic motion. Patients undergo CT followed immediately by MR simulations with the rectum empty. These data are fused and all soft tissue structures contoured based on the MR scan. 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. 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 delivery of modern 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 volumes of rectum receiving 65Gy and 40Gy are less than 17% and 35%, respectively. Additionally, the volumes of bladder receiving 65Gy and 40Gy are less than 25% and 50%, respectively. The volume of either femoral head receiving 50Gy should be less than 10%. 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. PTV coverage should result in at least 95% of the volume receiving the prescription dose. 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 resulting in the safe use of the numerical values presented for plan acceptance

Therapy Scientific Session — Room 617
IMRT Clinical Applications I

WE-E-T-617-01

A Reduction in Neutron Production Through the Use of a Flattening-Filter-Free Accelerator

S Kry*, U Titt, F Poenisch, O Vassiliev, M Salehpour, M Gillin, R Mohan, MD Anderson Cancer Ctr., Houston, TX

Purpose: High-energy photon treatments (E > 10-MV) are contaminated by neutrons that are produced in the accelerator head. These neutrons are detrimental as they deliver stray radiation dose to the patient, as well as activating components in the treatment vault, which irradiates the radiation therapist. A reduction in the neutron fluence may be achieved through the removal of the flattening filter. **Method and Materials:** A Varian 2100 accelerator was operated in 18-MV photon mode using the flattening filter and also without the flattening-filter. The neutron fluence was measured with moderated gold foils at several points in the patient plane. Additionally, an 8-field prostate IMRT treatment plan was generated in Eclipse version 6.5 for an anthropomorphic Rando phantom for both the flattening-filter and flattening-filter-free modes. **Results:** The neutron fluence per MU was found to be 20% lower in the flattening-filter-free mode. Furthermore, as the flattening-filter-free mode has a higher dose per MU on central axis, an IMRT treatment for a Rando phantom required only 3,724 MU as compared to 10,981 MU for the flattening-filter mode. For the Rando treatment there would be a reduction of over 70% in the number of produced neutrons. **Conclusions:** The neutron fluence per MU and per treatment was substantially decreased through the use of a flattening-filter-free accelerator. This corresponds to a reduction in the patient dose from stray neutrons, as well as a reduction in the activation dose to the radiation therapist. **Conflict of Interest:** This work was supported in part by a grant from Varian Medical Systems.

WE-E-T-617-02

Dosimetric Impact of Anatomic Variations for Head & Neck Cancer Patients Undergoing IMRT Treatment Analyzed by Deformable Imaging Registration

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Purpose: The anatomy in some head and neck cancer patients can vary significantly during the course of radiation therapy due to weight loss and/or tumor shrinkage. The purpose of this study is to investigate the dosimetric impact of such changes for patients who have had second CT imaging during their IMRT treatments. **Method and Materials:** Patients had second CT imaging at the request of their treating physician due to a change in the patients' anatomy. In order to focus on the dosimetric effect due to soft tissue changes only (excluding setup errors), the second CT was first registered to the planning CT using an in-house CT-to-CT translation-only bony-registration algorithm. Then the IMRT fields for the same treatment plan were applied to the second CT to obtain the dose distribution in the altered anatomy. In order to compare the dose distributions relative to the original plan, a voxel-by-voxel deformable image registration algorithm was used to map the dose distribution delivered to the 2nd CT back to the original treatment plan. The dosimetric effect can be then analyzed using the original contoured structures for critical organs and the planned targets. **Results:** There were significant variations in doses to some normal structures such as the ipsilateral parotid gland; while the mean dose to CTVs had only modest changes. In a preliminary analysis of 5 patients, the mean ipsilateral parotid dose increased 6.3±5.6 Gy(18.4%±16.5%), while the mean contralateral parotid dose only increased 0.7±1.4 Gy(2.4%±5.1%). The coverage for CTVs was reduced 3.1±3.5%. There was no significant change in the doses to spinal cord, brainstem, or mandible. **Conclusion:** We found noticeable changes in dosimetry for patients undergoing IMRT treatments, particularly in the ipsilateral parotid gland. With deformable image registration, we have demonstrated dosimetric changes for head and neck cancer patients during their courses of radiation therapy.

WE-E-T-617-03

Flattening Filter Free IMRT - First Experimental Results

U Titt*, O Vassiliev, F Poenisch, S Kry, R Mohan, M Gillin, The University of Texas M.D.Anderson Cancer Center, Houston, TX

Purpose: The purpose of this study is to determine if a flattening filter free clinical accelerator can be used for IMRT applications. Furthermore the performance of a treatment planning system, which has been commissioned for a flattening filter free machine, has been evaluated. **Method and Materials:** A treatment planning system ECLIPSE (Varian) was commissioned for a 6-MV flattening filter free clinical accelerator, using data resulting from Monte Carlo simulations and measurements. Treatment plans were created for a nasopharyngeal carcinoma case using CT-data of a Rando-phantom, for the filter free machine, and for a standard IMRT machine. A comparison of the treatment plans was performed by evaluating dose-volume-histograms (DVHs). The treatment plans were then delivered to a phantom containing films, and the resulting dose distributions have been compared. **Results:** Comparison of the DVHs from the filter free machine to the standard accelerator revealed better coverage of the PTV, while organs at risk, i.e. brainstem and spinal cord showed decreased dose values, when the filter free machine was used for treatment planning. Comparing the results of film irradiations showed systematically better penumbras and out of field doses in the flattening filter free irradiations, while the target coverage was comparable in both cases. **Conclusion:** The ECLIPSE treatment planning system is capable of creating IMRT plans for a flattening filter free clinical accelerator. Low energy (6-MV) IMRT treatment plans, have successfully been created and delivered to a phantom, showing that advantageous dose distributions can be achieved with a flattening filter free accelerator. Conflict of Interest: This research is supported in part by Varian Medical Systems.

WE-E-T-617-04

IMRT and Brachytherapy for Cervical Cancer

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Purpose: Radiotherapy of cervical cancer is usually delivered through a combination of external-beam and intracavitary-brachytherapy treatments. A portion of the external-beam treatment is often delivered with a midline block, either straight or tapered at the edges, to avoid overdosing the brachytherapy dose distribution. This study investigates the replacement of the midline block with intensity-modulated-radiation-therapy (IMRT), matching the IMRT dose to the biologically-equivalent brachytherapy dose distribution, while additionally achieving optimized target coverage and minimized critical organ doses. **Method and Materials:** CT scans of a female pelvic phantom were imported into a commercial treatment planning system (TPS) to calculate the dose distribution of a high-dose-rate (HDR) tandem and ovoid treatment delivering 650cGy to point A. A planning target volume (PTV), the rectum, and the bladder were segmented. The brachytherapy dose distribution was converted to its biologically-equivalent dose distribution, at 180cGy daily fractions, using the linear-quadratic equation and an α/β ratio of 10, by modifying the HDR source's radial-dose function (RDF) values. A set of IMRT fields, at 180cGy/fraction, was planned to deliver a dose of 720cGy to the target for each HDR fraction while accounting for implant dose. The IMRT fields geometry included two scenarios; AP/PA parallel-opposed fields, mimicking the conventional split-field pelvis treatments with a midline block, and a 5-field coplanar beam arrangement that had the potential to improve target coverage and reduce critical-organ doses. **Results:** The single-source RDF values were successfully modified to compute the biologically-equivalent dose distribution of the HDR treatment. The TPS was able to calculate IMRT field fluence maps, in both scenarios, to obtain dose volume histograms of the target and the critical organs as prescribed. **Conclusion:** It was demonstrated that IMRT doses distributions for cervical cancer treatment can be biologically matched to brachytherapy dose distributions, thus improving target coverage and sparing critical structures.

WE-E-T-617-05

Monte Carlo Dose Verification for MRI-Based Treatment Planning of Prostate Cancer

Z Chen*, J Yang, J Li, K Paskalev, C Ma and L Chen, Fox Chase Cancer Center, Philadelphia, PA, Penn State Cancer Institute, Hershey, PA

Purpose: Modern radiotherapy requires high accuracy for dose calculation and beam delivery. In this work, we used the Monte Carlo method to validate the dosimetry accuracy for MR based IMRT treatment planning for prostate cancer treatment. **Method and Materials:** Fifteen prostate cancer patients were scanned on both a CT simulator and a 0.23 T open MR scanner and the IMRT plans were made for these patients. Monte Carlo simulations were performed for these patients using homogeneous geometry based on CT and MRI, and heterogeneous geometry built based on CT numbers or different bulk densities for MR contoured bony structures. The homogenous density was chosen as 1.0g/cm3 and the density of bone was chosen in the range 1.5 – 2.0 g/cm3. Isodose distributions and DVH were used in comparison. **Results:** For coplanar IMRT treatments, the mean dose values of the GTV for homogeneous geometry based on CT was about 2% higher than those for heterogeneous geometry based on CT. The difference in the mean GTV dose between homogenous MRI and heterogeneous CT geometries was always less than 3%. After applying heterogeneity correction to the femurs for MRI, the difference was reduced to < 2%. The DVH curves agreed within 5% in dose or volume among these plans. For the critical structures, all the plans calculated using CT or MRI met our clinical acceptance criteria. For non-coplanar treatments, a maximum 7% discrepancy was found in the GTV dose between homogeneous and heterogeneous geometries due to the significant attenuation of the oblique beams going through the femurs. For MRI-based planning, the discrepancy was reduced to 2% if the femurs were assigned a bulk bone density in the dose calculation. **Conclusion:** Our results show that MRI-based IMRT planning meets the accuracy requirement for radiotherapy treatment of prostate cancer and it has been implemented clinically.

WE-E-T-617-06

Intra- and Inter-Planner Dosimetric Variations in Inverse Planning of IMRT

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Purpose: To investigate intra- and inter-planner variations in dose-volume output in IMRT with identical input parameters (volumes, beams and constraints) for estimation of quality assurance in the treatment planning process. **Method and Materials:** Five collaborators with Helios/Eclipse TPS and Varian accelerator were chosen. The PTV and OAR of prostate, lung and head and neck cases were copied and distributed with instructions having identical beam orientations, beam energy and dose volume constraints. Each planner repeated the treatment planning process three times with inhomogeneity correction to see intra-planner variation. Data were electronically collected for analysis. The study was blind such that planners had no access to the data other than their own. For quality assurance, PDD, dose profiles, leaf leakage etc. were also evaluated. **Results:** There were large variations in the IMRT plans reflected by the DVH among planners even with identical dose and constraints. The PTV coverage as well as OAR was unusually broader. Based on the style and weight in optimization, it provided very different coverage for PTV and other structures. The inter-planner variations in PTV as large as 20% and in OAR up to 60% were found in this study. Similar variations were also noted for the intra-planner study. Every time optimization is performed even with same constraints, the DVH output was significantly different. Differences up to 26% were noted in intra-planner study for all cases. There was no correlation among planner and the cases indicating a random pattern. **Conclusion:** Significant intra- and inter planner variation exists for all cases indicating that for same constraints the outcome cannot be guaranteed to be identical. This study raises significant concerns on the quality of optimization as they cannot converge at the same point. Hence the patient treatments are subject to random variations reflected with treatment planning which could vary significantly.

WE-E-T-617-07

Topographic Treatment Planning and Delivery

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Purpose: The purpose of this work was to develop a leaf-sequencing algorithm for fixed-gantry (*non-rotational*) treatment delivery on a helical tomotherapy system. Topographic delivery creates intensity-modulated fields by moving the couch at a constant velocity relative to 10-mm wide fan-beam that is modulated with a 64-leaf binary MLC. **Method and Materials:** Inverse treatment planning was performed using Pinnacle 7.4. The calculated intensity maps were exported to a custom leaf-sequencing program that modeled the leaf sequences as a tap moving over a collection of bottles. The leaf-sequencing algorithm was developed using a tap analogy in a step-wise process. The initial back edge and final front edge of each step were determined from Newton's Equations of Motion. Once the edges of the steps were established, the number of covered bottles was calculated. The final step was the determination of the time required to fill the each bottle with the prescribed dose from Fourier's Convolution Theorem. **Results:** The leaf-sequencing algorithm was initially tested using artificially constructed dose distributions that were compared with the calculated deliverable dose distributions based on the algorithm output. The difference between the theoretical doses and the deliverable doses was much less than 1 percent. The agreement between the Pinnacle intensity maps and the deliverable doses were generally less than 1 percent, with the exception of near the field edge where the intensity map values decreased by 80% in one pixel width. **Conclusion:** A leaf-sequencing algorithm was developed for fixed-gantry treatment delivery on a helical tomotherapy system. The developed algorithm produced calculated deliverable distributions that agreed remarkably with the artificially constructed distributions. Accuracy of the leaf sequencing algorithm will be verified by the film dosimetry method and will be presented at the meeting.

Therapy Symposium Room 6E
Multiplanar Dosimetry without Film Processors

WE-E-T-6E-01
Multidimensional Dosimetry Without Film Processors

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Introduction: Radiographic film has been a mainstay for quality assurance procedures within radiation oncology departments. Prior to 3D conformal therapy, treatments were planned using kilovoltage portal films (simulator films). After the introduction of 3D conformal therapy, this function was shifted to digitally reconstructed radiographs which were often printed on radiographic film. Patient positioning verification was conducted using megavoltage portal films, and multidimensional dose distribution quality assurance relied on film-based dosimetry. Many clinics are taking advantage of modern imaging and computer equipment to remove radiographic film from routine clinical operations. This is occurring simultaneous to the wide-spread adoption of intensity modulated radiation therapy (IMRT). The complexity of IMRT has led to the requirement of direct validation of the patient's treatment delivery. This often includes a multidimensional measurement of the dose distribution. Clinics that have removed radiographic film from their routine process may elect to remove the film processors. Radiology is also moving towards a filmless process, so the number of available film processors in hospitals may in the near future be limited. Many medical physicists responsible for IMRT QA will find themselves without a basic dosimetry tools so alternative techniques need to be established.

This symposium will present three alternatives to radiographic film for multidimensional dose distribution measurements; multipoint electronic dosimeters; 3D dosimeters, and radiochromic film. The goal of the symposium is to educate the attendees in the methods, advantages, and challenges inherent to each system.

Multipoint electronic dosimeters: This will be a survey of commercially available multipoint electronic dosimeters that can be used for IMRT quality assurance (QA) work. These devices fall into the following categories: arrays of silicon diodes; unsealed, large area, pixel segmented, air ionization chambers; electron portal imaging devices that use liquid ionization chambers and amorphous silicon detectors; and metal-phosphor-screen imaging systems. The basic operating principles will be presented. The following characteristics will be compared: detector spatial resolution, signal acquisition time, measurement and data storage dead time, system dynamic range, linearity of detector response, measurement of dose or fluence, calibration procedure and its longevity, compatibility with treatment planning systems and linear accelerators, applicability to dynamic and static delivered IMRT, slice- and helical-tomotherapy, analysis software and functionality, ease of use, and overall QA time.

Status of 3D dosimetry techniques: Several 3D dosimetry systems have been proposed in recent years, but their acceptance into widespread clinical use has been slow. Primary reasons include lingering practical difficulties, limited access to specialized equipment, expense, and lack of convenience. Despite slow acceptance in the clinic, the field of 3D dosimetry is accelerating in innovation and promise. Several new 3D dosimetry materials have been proposed with striking performance characteristics. Significant advances have also been made in technologies to image 3D dose distributions, including both optical and MR techniques. In this lecture we will review these and other developments in an attempt to explore the present state of the art.

Radiochromic Film: Radiochromic film (RCF) has been demonstrated to be precise and accurate dosimeter for the acute delivery of high doses (5-100 Gy). RCF provides energy-independent tissue-equivalent dose response in the megavoltage photon range, high spatial resolution, and insensitivity to visible light. RCF is convenient to handle, mark, or cut, and the films can be immersed in water phantoms. Until recently, RCF was inadequate for clinical applications requiring low doses (1-400 cGy), such as the measurement of a single fraction of IMRT delivery for patient specific QA. Due to the fact that multileaf collimator systems behave more accurately when delivering IMRT segments with increasing monitor units, recording doses under clinical conditions is crucial to the validity of the measurement. The practice of scaling up the monitor units of a delivery to better match the sensitivity of a dosimeter is unacceptable as it prevents accurate characterization of the delivery. Very recently, a novel formulation of RCF (trade-named EBT RCF from I.S.P. Inc.) with greatly increased absorbed dose sensitivity has been introduced. This new RCF is based on a novel polymerizing microcrystalline sensitive layer with improved sensitivity for densitometry systems at wavelengths of about 635nm. The sensitivity of the film has been increased to range between 2 and 800 cGy, making it ten times more sensitive than previous RCF and well suited to IMRT QA measurements. This new dose range is comparable to those obtainable with commercial radiographic films; however, RCFs are self-developing and do not require film processors with their associated maintenance and QA. The self-developing nature of RCF makes it potentially more accurate, as well, since it obviates the need for precise chemical and thermal control of post-exposure processing needed with conventional silver-based films. The new film also demonstrates a faster saturation of optical density after irradiation, allowing for rapid scanning and evaluation.

Workshop Room 608
Digital Radiography QC Workshop

WE-E-W-608-01
DR QC Workshop

J Seibert*[1], L Goldman*[2], (1) UC Davis Medical Center, Sacramento, CA, (2) Hartford Hospital, Hartford, CT

Quality control (QC) of digital radiographic systems requires qualitative and quantitative assessment to determine readiness for clinical image acquisition. Vendors of computed and direct radiography will demonstrate, in a “hands-on” workshop, methods used for implementing QC testing, including a description of radiographic phantoms, testing procedures, analysis of phantom images, pass/fail criteria, and methods of documentation. Attendees will have an opportunity to see quality control procedures and analysis via direct demonstration on each vendor’s QC workstation, and be able to interact with the vendor representative in small groups during the workshop. A technology review of each digital system including details of system specifications, unique imaging capabilities, and QC will be presented.

Participants: Agfa, Eastman Kodak, Fujifilm, General Electric, IDC, Konica

Educational Objectives:
1. Learn about digital radiography equipment quality control procedures
2. Understand phantom designs and what the phantoms are testing
3. Determine acquisition parameters used for QC testing
4. Analyze sample data for “hands-on” QC analysis
5. Discuss issues related to exposure index, image artifacts, and QC data tracking

THURSDAY, JULY 28

Imaging Continuing Education CourseRoom 618
CE: Breast Imaging Physics and Technology - IV

TH-A-I-618-01
Practical and Regulatory Issues for Screen-Film Mammography Physics Surveys
R Pizzutiello*, Upstate Medical Physics, Victor, NY

Purpose: To acquaint the medical physicist with a number of practical and regulatory issues that may be encountered when providing medical physics support to screen-film mammography (SFM) facilities. **Method and Materials:** Case studies will be presented that demonstrate potential issues (problems) that medical physicists have encountered during with mammography annual surveys, equipment evaluations, changes in screen-film systems, changes in facility personnel, and other real-world situations. The applicable regulatory background will be presented for each case, as well as potential pitfalls and possible solutions. Recent changes in FDA interpretation of SFM artifact testing, and efforts of professional organizations to address this issue are presented. **Results:** The applicable scientific, professional and regulatory background will be presented for each case. Potential pitfalls and possible practical solutions will be presented. **Conclusion:** This presentation should assist medical physicists as they provide service to mammography facilities

Imaging Continuing Education Course Room 617
CE: PET Physics and Technology - IV

TH-A-I-617-01
PET Site Planning and Radiation Safety
J A Anderson*, UT Southwestern Medical Ctr at Dallas, Dallas, TX

PET and PET/CT imaging are rapidly becoming standard-of-care for the diagnosis and staging of many medical conditions. This has led to a dramatic increase in the number of 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. To address these difficulties, the designer needs to thoroughly understand the workflow in such 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. These topics will be discussed and the basic design data for high-energy photon shielding will be reviewed. The AAPM has established a task group on PET and PET/CT Shielding Requirements. The preliminary report from this task group will be discussed and specific examples for the design of PET shielding will be given.

Educational Objectives:
1. To provide an overall understanding of the workflow, exam procedures, patient workloads, and radiation safety practices at PET and PET/CT imaging facilities.
2. To review the approaches and necessary data for calculating shielding requirements for PET isotopes.
3. To discuss the preliminary report of the AAPM task group on PET and PET/CT Shielding Requirements and provide some specific examples of the methods described in that report.

Imaging Continuing Education Course Room 609
CE: Digital Imaging Systems, Processing, Analysis and Display - IV

TH-A-I-609-01
Design and Performance Characteristics of Digital Radiographic Receptors
J Seibert*, UC Davis Medical Center, Sacramento, CA

Digital radiographic receptors have been available in medical imaging for the last two decades, but are just now becoming commonplace in the clinical environment in conjunction with the deployment and implementation of electronic image acquisition, display and archiving in radiology and the medical enterprise. Therefore, a need exists to identify the design and performance characteristics of these detectors to determine an appropriate system for a specific or general clinical task, and to keep abreast of the technological changes and innovations that are constantly occurring. Devices include Computed Radiography (CR) using photostimulable phosphor detectors, Charge-Coupled-Device (CCD) and Complementary Metal-Oxide Semiconductor (CMOS) cameras optically coupled to a phosphor scintillator, slot-scan CCD technology with linear or rectangular arrays, and thin-film-transistor (TFT) two-dimensional arrays coupled to phosphor converters and photodiodes or semiconductor detectors. Because digital devices produce images that are inherently signal to noise ratio limited (rather than contrast limited as is the case with analog film), each is designed to provide high spatial resolution simultaneous to delivering high detective quantum efficiency, and at the same time attempting to achieve low radiation dose. Some digital systems do this better than others. Quantitative analysis yields performance metrics including modulation transfer function (MTF), noise power spectrum (NPS), and detective quantum efficiency (DQE). Detector system applicability to a given imaging task, system cost, portability, image handling and practicality are issues that must be considered prior to purchase and implementation. This presentation gives the attendee an overview of these issues.

Educational Objectives:
1. To understand the variety of digital detector technologies for medical radiography and mammography
2. To provide an overview of each detector from a physics/quantitative perspective
3. To compare the detectors in terms of image quality and radiation dose
4. To review some issues regarding acceptance testing and periodic quality control
5. To summarize the pros and cons with respect to user function, system integration, and costs

Imaging Continuing Education Course Room 611
CE: Computed Tomography Physics and Technology - IV

TH-A-I-611-01
ACR Accreditation Physics Tests
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The Americal College of Radiology introduced an accreditation program for Computed Tomography (CT) in 2002. The CT accreditation application requires the participation of a qualified medical physicist (with specific credentials) in order to submit appropriate phantom images and radiation dose measurements for CT scanners. Examples of acceptable CT accreditation phantom images will be presented, along with examples of the more commonly made mistakes. A brief review of the dosimetry procedures to follow, and pitfalls to avoid, will also be covered. Special attention will be directed toward the accreditation process for multi-slice CT scanners.

Therapy Continuing Education Course Room 6E
CE: QA for IMRT - IV

TH-A-T-6E-01
How Do We Decide on Tolerance Limits for IMRT Quality Assurance?
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 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 6C
CE: Photodynamic Therapy

TH-A-T-6C-01
Photodynamic Therapy: Fundamentals and Dosimetry
TC Zhu[1]*, JC Finlay[1], B Wilson[2], 1Univ Pennsylvania, Philadelphia, PA, 2Princess Margaret Hospital, Toronto, ON, CA

Photodynamic therapy (PDT) is an emerging cancer treatment modality based on the interaction of light, a photosensitizing drug, and oxygen. PDT has been approved by the US Food and Drug Administration for the treatment of microinvasive lung cancer, obstructing lung cancer, and obstructing esophageal cancer. Studies have shown some efficacy in the treatment of a variety of malignant and premalignant conditions including head and neck cancer, lung cancer, mesothelioma, Barrett's esophagus, prostate, and brain tumors. Unlike radiation therapy, PDT is a non-ionizing radiation that can be used repeatedly without cumulative long-term complications since it does not appear to target DNA.

Various photosensitizer drugs have been developed. Most of the drugs are so called Type II photosensitizers, where the active agent of phototoxicity is induced by the production of singlet oxygen or active oxygen derivatives through light activation. The first-generation photosensitizer, haematoporphyrin derivative (HPD), is a mixture of porphyrin monomers and oligomers that is partially purified to produce the commercially available product, Photofrin®. HPD is photochemically activated by the absorption of tissue-penetrating light at λ 630 nm (red) and is the only FDA approved photosensitizer. HPD-mediated PDT has several clinical disadvantages, including prolonged skin photosensitivity (4 weeks), relatively low quantum yield of singlet oxygen, and a limited depth of associated tissue damage of 2-5 mm. Second generation photosensitizers (e.g., mTHPC, TOOKAD, and MLu) overcome these shortcomings with higher quantum yield, lower skin toxicities, and deeper penetration.

There has been tremendous progress in photodynamic therapy dosimetry. The simplest clinical light dose prescription is to quantify the incident fluence for patients treated with a given photosensitizer injection per body weight. However, light dose given in this way do not take into account the light scattering by tissue and usually underestimate light fluence rate. Techniques have been developed to characterize the tissue optical properties and the light fluence rate in-vivo. Other optical spectroscopic methods have been developed to characterize tissue absorption and scattering properties, which in term provide information about tissue oxygenation and drug concentration. Fluorescence techniques can be used to quantify drug concentration and potentially photobleaching rate of photosensitizers.

The objective of this course is to present a brief review of the issues related to the application of photodynamic therapy. In particular, we review the current start of art of techniques to quantify light fluence, drug concentration, and tissue oxygenations, and PDT outcome.

Educational Objectives:
1. To explain the basic principle of photodynamic therapy.
2. To discuss the various photosensitizer drugs.
3. To review techniques for PDT light delivery for surface and interstitial applications.
4. To review current state of art in PDT in-vivo light dosimetry, light-tissue interaction, and the light fluence distributions in turbid medium.
5. To review PDT dosimetry techniques to characterize tissue optical properties, drug concentration, tissue oxygen concentration, and PDT efficacy.

Imaging Continuing Education Course Room 618
CE: Radiographic and Fluoroscopy Physics and Technology - IV

TH-B-I-618-01
Fluoroscopy Acceptance Testing: Technical Considerations for Image Quality and Dose
P Rauch*, Henry Ford Health System, Detroit, MI

Modern fluoroscopy imaging equipment, especially that which is intended for vascular and cardiac imaging, are "Systems" operating under microprocessor control. They are designed to simultaneously monitor the beam attenuation, the detector exposure rate, and the contrast-to-noise ratio and automatically make adjustments to many parameters controlling x-ray production, beam filtration, video electronics, digital image processing, and image presentation. In the days of invariant beam filtration, anti-isowatt fluoroscopic power curves, fixed optical apertures, single pre-set image intensifier input exposure rate, and pre-defined image display parameters it was relatively straight-forward to use simple attenuating materials and test patterns to simulate patient attenuation or to evaluate image quality. Today it is not that simple and a system can perform quite differently (in terms of both image quality and dose) when evaluated using inanimate test objects as compared to when the system is imaging patient anatomy.

When attempting to evaluate the performance of a modern fluoroscopic imaging system, the first challenge is to gain an understanding of how the system is designed, to determine which system variables are dynamically controlled, and to identify the trigger points for these variables. The second and greater challenge is to determine an objective test methodology that would accurately and reproducibly create machine settings that are the same as those produced during patient procedures. This presentation will systematically describe the functions of the major system components including automatic exposure rate control, variable pulse-rate fluoroscopy and associated kV-mA power curves, spectral beam filtration, spatial beam shaping, and other factors that affect the ability of the imaging system to deliver optimum diagnostic images at moderate patient dose. It will also show how the design of a fluoroscopic imaging system impacts the functional performance, the image quality, and the patient dose. Specific acceptance testing methodology will be covered in another presentation.

Educational Objectives:
1. Provide an understanding of modern fluoroscopic imaging system component design and functionality
2. Show how limitations in the design and functionality of the operator interface can have an adverse impact on functional performance, image quality and patient dose

TH-B-I-618-02

Fluoroscopy Acceptance Testing: Test Procedures & Performance Criteria

E Nickoloff*, Columbia Univ, New York, NY

The primary goal of this presentation is to examine appropriate physics testing procedures for modern fluoroscopy equipment. Modern systems may contain new features like significant copper filtration, flat panel image receptors, and various automated systems which affect their performance characteristics. Regardless, fluoroscopy acceptance testing should be divided into the following categories: mechanical components, radiation measurements, electronic control features, image quality, software selections, regulatory compliance, display monitors, PACS systems and safety concerns. The mechanical system tests should include: the central beam alignment, isocenter accuracy, collimation accuracy, 3-D rotational imaging and system component motion. Radiation tests should at least measure patient entrance surface and image receptor input exposure rates determined with a range of attenuation materials (either acrylic slabs or the NYS metallic attenuators). The protection against scattered radiation should be evaluated for the more penetrating x-rays of modern units. Electronic control checks should include: kVp accuracy, Automatic Brightness Control (ABC) operations, examination of radiation pulse widths & frequency and true Field-of View (FoV) sizes. Image quality measurements should include high contrast resolution employing both bars patterns and screen meshes; the effects of filtration, magnification, detector element (del) and focal spot blur will be discussed. Low contrast measurements often utilize an aluminum penetrameter, ACR fluoroscopy phantom and different contrast-detail devices. The impacts of software features upon image quality like frame averaging, dynamic range compression, contrast adjustment and edge enhancement are important. Regulatory compliance may involve new criteria for HVL, and modern equipment can sometimes present difficulties with measurement of some parameters. Display monitor performance can be determined with light meter measurements and subjective evaluations using test patterns. PACS checks involve image transmission, archival storage and retrieval without degradation. Safety checks involve the assessment of various collision sensors, interlocks, electrical safety and other features. This presentation is directed towards providing insights, limitations and approaches to physics assessments of modern fluoroscopy systems.

Imaging Continuing Education Course Room 617

CE: Magnetic Resonance Imaging Physics and Technology - IV

TH-B-I-617-01

Advanced MRI - An Overview of Techniques and Applications

E Jackson*, UT M.D. Anderson Cancer Center, Houston, TX

The wide range of contrast mechanisms available in MRI has made it the modality of choice in many soft tissue imaging applications. Over the past decade, improvements in gradient and radiofrequency subsystems have allowed for dramatic increases in image acquisition rates and improved system stability. As a result, non-invasive MR techniques for assessing tissue function, in addition to providing anatomic detail, have become common. This presentation will provide an overview of advanced MR techniques that are, or are becoming, common in clinical practice.

Assessing changes in ^{1}H diffusion: On virtually all state-of-the-art high-field MR scanners, diffusion imaging techniques are available. In diffusion imaging, diffusion-sensitizing gradients are applied during an echo-planar spin-echo sequence to sensitize the acquired signal to the rate of proton diffusion. Diffusion-weighted images are very commonly used in the assessment of acute stroke and are also widely used in oncology. In addition, by appropriately applying the diffusion-sensitizing gradients, diffusion tensor information can be obtained in order to non-invasively map white matter tracts.

Assessing biochemical changes: Automated magnetic field homogeneity adjustment, high quality localization, and efficient water suppression techniques have allowed for routine acquisition of 1H MR spectroscopy data in brain and, more recently, in prostate. Other applications, particularly in breast, are also actively being pursued and will be discussed.

Assessing the microvascular environment: Two techniques have been used to assess changes in the microvascular environment due to natural progression of disease or, more commonly, in response to therapeutic interventions. The first is dynamic contrast enhanced MRI, in which T1-weighted images are acquired rapidly before, during, and following the administration of a bolus of paramagnetic contrast agent. The kinetics of the contrast agent uptake are analyzed using a variety of techniques, including two-compartment pharmacokinetic modeling, to assess changes in microvascular permeability and volume. The second technique, dynamic susceptibility change MRI, obtains ultrafast T2*-weighted imaging before, during, and following a bolus paramagnetic agent injection. The decrease in signal intensity, concomitant to the dephasing of spins as the paramagnetic agent passes through the microvasculature, is proportional to the regional blood volume and deconvolution techniques can be used to determine the blood volume, flow, and permeability.

Assessing areas of neuronal function: Blood oxygen level dependent (BOLD) techniques, using ultrafast echo-planar gradient-echo imaging, are used to indirectly map areas of neuronal activation and might also be used to assess changes in tissue oxygenation by detecting changes in the local oxyhemoglobin-to-deoxyhemoglobin ratios. Such techniques are being used in presurgical planning and in basic neuroscience research in areas such as memory, expressive and receptive speech, visual-spatial processing, and other cognitive processes.

In this review, the basic physics and acquisition techniques for each of the above applications will be reviewed and selected clinical applications provided.

Educational Objectives:

1. Understand the basic physical and physiological principles of advanced MR techniques used to assess changes in microvascular parameters, cellular volume, and the biochemical status of tissue.
2. Develop an awareness of common applications of these advanced MR techniques.
3. Understand the primary limitations of each technique.

Imaging Continuing Education Course Room 609

CE Series: Ultrasound Imaging Physics and Technology: Contrast

TH-B-I-609-01

Imaging Ultrasound Contrast Agents

M Bruce*, Philips Medical Systems, Bothell, WA

Purpose: Existing Doppler ultrasound techniques are capable of detecting blood flow in large vessels with velocities high enough (>3 cm/sec) to enable removal of tissue signals. Microbubble ultrasound contrast agents can be administered intravenously to increase the backscatter from blood. The nonlinear behavior of ultrasound contrast agents enable discrimination from tissue both nearly stationary microbubbles in the microcirculation and higher velocity microbubbles in the larger vasculature. The visualization of blood flow in both the macro- and micro-circulation has been used to assess organ function and characterize tumors. **Method and Materials:** Imaging techniques for ultrasound contrast agents have been developed utilizing both the nonlinear and transient nature of contrast agents. These techniques are based on detecting microbubble nonlinear responses to the acoustic field of diagnostic ultrasound. Different multi-pulse transmit sequences will be described that have been used detect the nonlinear activity of the microbubbles (harmonic imaging, pulse inversion, amplitude modulation, and coded excitation). Only low amplitude acoustic fields may be used for interrogation to avoid bubble destruction and enable continuous contrast agent imaging. The difficulties of detecting nonlinear activity with low excitations are addressed. Doppler imaging techniques are used in cases where transient properties of contrast agents are to be imaged. With these techniques high acoustic amplitude is used to intentionally destroy the contrast microbubbles and form an image. Once the bubbles in a region are destroyed, the user must wait for the area to be replenished before forming another image or move to a new imaging plane. **Results:** While destruction techniques have an excellent signal to noise ratio (SNR), clinical use is difficult due to the destruction of contrast agent. Nonlinear imaging techniques are clinically easier to use, but suffer from SNR and are often penetration limited. A number of different ultrasound contrast agents have been approved for clinical use in Europe and Asia and are in the

Federal Drug Administration approval process in the US. Most these contrast agents can be imaged in real-time using the nonlinear imaging techniques. **Conclusion:** Ultrasound contrast agents can be used to image blood flow in both the micro- and macro- circulations. Clinical examples of imaging ultrasound contrast agent with both low and high amplitude techniques will be presented for both radiology and cardiology applications.

Imaging Continuing Education Course Room 611
CE: Radiation Safety and Risk Management - IV

TH-B-I-611-01
Science Behind Proposed ICRP Recommendations: Dosimetric Quantities and Units Used in Radiation Protection

C Borras*, George Washington University, Washington, DC

The International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) have developed two types of special dosimetric quantities for radiation protection: those that are related to risk and demonstrate compliance with exposure limits, and operational quantities that are used in monitoring and measuring external exposure and intakes of radionuclides. All are based on mean absorbed dose with its distributions in time and in linear energy transfer (linear collision stopping power).

In Publication 26 (1977), ICRP introduced the concepts of *dose equivalent* and *effective dose equivalent* to take into account the varying effectiveness of different radiations (the Q factors) and the variations in radiation sensitivity of different tissues (6 were specifically considered) for the induction of stochastic effects (the weighting factors, w_T). In Publication 60 (1991), the ICRP introduced *equivalent dose*, *effective dose* and the subsidiary quantities *committed dose* and *collective dose*. Q factors were superseded by w_R values and the number of tissues was increased to 12, with new values for w_T. In 2005, the ICRP proposes the terms *radiation-weighted dose, effective dose, committed dose* and *collective effective dose.* Based on new scientific evidence, w_R values are unchanged for photons and alphas, but have changed for neutrons and protons. w_T are different for the gonads, the breast an the "remainder" (the treatment of which has also changed); the number of tissues has increased to 14.

The operational quantities for external exposure, defined by ICRU (1993, 2001), include *ambient dose equivalent* and *directional dose equivalent* for area monitoring, and *personal dose equivalent* for individual monitoring. For internal exposure, the ICRP proposes to use activity quantities in combination with dose coefficients based on physiological models and 4-D computations.

The unit for all the quantities listed above is the Sievert (although the ICRP would like a different unit for the *radiation-weighted dose*).

The weighting factors and the dosimetric quantities based on w_R and w_T relate only to stochastic health effects, cancer induction and hereditary disease. The risk factors, from which w_R and w_T values are derived, have been obtained from epidemiological and experimental radiobiological data in the medium and higher dose ranges and have been extrapolated to the lower dose ranges using the linear no threshold model, which bears a high degree of uncertainty. The assumed linearity and additivity are, however, necessary conditions for all the dosimetric considerations.

Effective dose is to be used by regulators for occupationally exposed workers and members of the public, where doses are assumed to be low. At doses above about 0.5-1 Sv, tissue reactions (deterministic effects) may occur. At these levels, the dosimetric quantity to use is the absorbed dose in the irradiated tissue modified by the radiobiological effectiveness of the radiation for the biological endpoint of concern. The unit is the Gray.

Effective dose should not be used for retrospective evaluation of exposed populations or to assess individual risks, as is the case in medical exposures, which are not subject to dose limitations.

Educational Objectives:
1. To understand the dosimetric concepts involved in radiation protection.
2. To understand the uses of and the limitations and uncertainties associated with the dosimetric quantities.

TH-B-I-611-02
The Science Behind The ICRP 2005 Recommendations: Biological and Epidemiological Information

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The ICRP 2005 Recommendations are stated to be "based on a simple, but widely applicable, general system of protection that will clarify its objectives and will provide a basis for the more formal systems needed by operating managements and regulators". Underlying each of the broad areas of recommendation is a series of Foundation Documents that provide details of the most recent and/or appropriate scientific research in support of the recommendations. This presentation will focus on the approaches for quantitating health effects attributable to radiation exposure and the biological mechanisms that underlie these effects. The adverse health effects are grouped as (1) tissue reactions (2) cancer development in exposed individuals and heritable disease in their offspring. For considerations of tissue injury, ICRP has conducted a comprehensive review of experimental and epidemiological studies to revisit current estimates of thresholds for tissue reactions (deterministic effects) and consider revising these. For hereditary risks, ICRP has significantly modified its approach by using spontaneous human mutation rates in conjunction with radiation-induced mutation rates from mouse studies. In addition, hereditary risks are considered up to the second generation only. The overall result is a reduction in the genetic risk that will tend to reduce the value of tissue weighting factor for gonads. New epidemiological data on cancer mortality and incidence have been considered by ICRP and the broad conclusion is that the linear no threshold model remains as the best overall fit to the data. An important component of such a conclusion is that extensive data on cancer incidence are available from the A-bomb Life Span Study (LSS); these provide more accurate diagnosis and take account of relatively high prevalence but low mortality tumors. In addition, models were developed to facilitate transport of risk across populations, particularly based on data from the LSS population. The risk models also incorporated the concept of quality of life detriment, which is a departure from the detriment based on mortality alone. The recent data that impacted the value of DDREF were reviewed, but it was concluded that the current value of 2 was compatible with both human and laboratory animal data. A review of data for the production of non-cancer diseases after radiation was conducted, particularly for the LSS. While it is clear that there is an increase in several such diseases, the data available are not sufficient for their inclusion in the estimation of detriment at doses in the range of a few tens of mSv. Some of these judgments will be considered in greater detail during the presentation.

Educational Objectives:
1. To understand the biological data that for the basis for radiation risk assessments.
2. To understand how new data have necessitated a reconsideration of the basis for radiation protection standards.

This abstract has been reviewed in accordance with EPA guidelines but it does not necessarily reflect EPA policy.

Therapy Continuing Education Course Room 6E
CE: Monte Carlo for Radiotherapy - II

TH-B-T-6E-01
Monte Carlo Applications in Conformal, IMRT and 4D Clinical Treatment Planning: Pitfalls and Triumphs

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Due to its ability to accurately model dose distributions for arbitrarily complex treatment delivery scenarios and patient geometries, it is highly probable that over the next few years the use of Monte Carlo in routine clinical planning will become substantially more widespread. 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 conventional algorithm based planning. We will demonstrate the utility of Monte Carlo with respect to improved dose calculation accuracy (versus conventional algorithms) in heterogeneous patient tissues, and illustrate how a properly benchmarked Monte Carlo system can play a unique role in the modeling of complex delivery procedures, such as IMRT. In particular, the ability to effectively model the dosimetric consequences of the detailed the multi-leaf collimator (MLC) geometry with Monte Carlo will be demonstrated. Finally, we will show how Monte Carlo can be applied to compensate for organ motion in 4D treatment planning without an increase in computation time. In addition to illustrating the role of Monte Carlo in complex treatment planning, an important focus of this course will be to provide guidance to clinical physicists on practical issues associated with the implementation, verification and clinical use of Monte Carlo systems.

Educational Objectives:
1. To familiarize clinical physicists with Monte Carlo applications for routine clinical treatment planning.
2. To understand the dosimetric influence of Monte Carlo in different anatomical sites and to become familiar with the potential clinical outcome benefits of Monte Carlo.
3. To understand some of the issues that clinical physicists face in the implementation and experimental verification of Monte Carlo treatment planning systems.
4. To understand the use, benefits and limitations of Monte Carlo for IMRT optimization and QA.
5. To become familiar with the role of Monte Carlo in motion compensated (4D) treatment planning.

Therapy Continuing Education Course Room 6C
CE: Imaging for Treatment Planning - IV

TH-B-T-6C-01
CT: Single and MultiSlice
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Computed tomography (CT) simulator combines functionality of a conventional simulator with features and image processing and display tools of a three-dimensional radiation therapy treatment planning (3D RTTP) system. Due to this ability, CT-simulators have become the primary imaging modality for treatment planning in radiotherapy. Another development in CT has been the rapid replacement of single slice scanners with multislice CT in diagnostic radiology departments. This process is also beginning in radiation therapy where multislice CT scanners also offer several advantages. This presentation: 1) describes multi-slice CT technology; 2) describes potential advantages of multi-slice CT in radiation oncology; and 3) describes CT-simulation process with multi-slice CT scanners.
One of the greatest limitations in the CT-simulation process has been the heat storage capacity of x-ray tubes in single slice CT scanners used for patient imaging. Radiotherapy treatment planning scans demand large number of images of high quality. Large number of images and very good image quality are needed for tumor volume and critical structure delineation and for verification of accuracy of patient treatments. Single slice scanners were often unable to acquire large number of high quality images efficiently. This resulted in a perpetual compromise between number of images and image quality used for radiotherapy treatment planning.
Multi-slice CT is typically not associated with x-ray tube heat storage problems and virtually unlimited numbers of high quality images can be acquired. This improvement in number of images and image quality has a potential to affect several aspects of radiotherapy treatment planning process. Better image quality allows improved tumor and normal structure delineation. The ability to acquire increased number of images also allows acquiring thinner slice thicknesses than with the single slice scanners. Thinner CT images greatly improve quality of digitally reconstructed radiographs (DRRs) and ability to verify patient positioning for treatment planning. In addition to better DRRs, CT data sets acquired on multislice scanners can have isotropic resolution enabling multiplanar contouring and more accurate definition of anatomical structures.
Multi-slice CT also acquires images much faster than single slice scanners. The faster scan capability has spun development of new image acquisition techniques generally referred to as dynamic-CT, 4D-CT, or 5D-CT. Dynamic CT acquisition enables capturing of tumor motion as a function of patient breathing. This information can then be used in the treatment planning process for improved targeting of tumor volumes and sparing of critical structures.
Multislice CT has resulted in a situation where CT technology has surpassed the capabilities of treatment planning system. CT scanners can produce much more information than treatment planning systems and current treatment planning processes can manage efficiently. Presently, implementation of multislice technology and exploitation of its benefits in radiotherapy requires a balance between the volume of collected data and the ability of treatment planning systems to process this data.

Educational Objectives:
1. to describe multi-slice CT technology;
2. to describe potential advantages of multi-slice CT in radiation oncology; and
3. to describe CT-simulation process with multi-slice CT scanners.

Therapy Continuing Education Course Room 6B
CE: The Radiological Physics Center's QA Activities

TH-B-T-6B-01
The Radiological Physics Center's QA Activities
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Purpose: To describe the mission and activities of the Radiological Physics Center (RPC). **Method and Materials:** The RPC was founded in 1968 under an agreement between the AAPM and the Committee for Radiation Therapy Studies (CRTS). The agreement called for the AAPM to solicit applications to form a QA center that would be a resource in radiation dosimetry and physics for cooperative clinical trial groups and all radiotherapy facilities that deliver radiation treatments to patients entered onto cooperative group protocols. The RPC has functioned continuously for 36 years to support medical physicists and radiation therapy departments. **Results:** The RPC's mission has changed only slightly over the years. The primary responsibility is to assure NCI and the cooperative groups that the participating institutions have adequate quality assurance procedures and no major systematic dosimetry discrepancies, so that they can be expected to deliver radiation treatments that are clinically comparable to those delivered by other institutions in the cooperative groups. To accomplish this, the RPC monitors the basic machine output and brachytherapy source strengths, the dosimetry data utilized by the institutions, the calculation algorithms used for treatment planning, and the institutions' quality control procedures. The methods of monitoring include on-site dosimetry review by an RPC physicist, and a variety of remote audit tools. During the on-site evaluation, the institution's physicists and radiation oncologists are interviewed, physical measurements are made on the therapy machines, dosimetry and quality assurance data are reviewed, and patient dose calculations are evaluated. The remote audit tools include 1) mailed dosimeters (TLD) evaluated on a periodic basis to verify output calibration and simple questionnaires to document changes in personnel, equipment, and dosimetry practices, 2) comparison of dosimetry data with RPC "standard" data to verify the compatibility of dosimetry data, 3) evaluation of reference and actual patient calculations to verify the validity of treatment planning algorithms, and 4) review of the institution's written quality assurance procedures and records. Mailable anthropomorphic phantoms are also used to verify tumor dose delivery for special treatment techniques. Any discrepancies identified by the RPC are pursued to help the institution find the origin of the discrepancies and identify and implement methods to resolve them. **Conclusion:** While conducting these reviews, the RPC has amassed a large amount of data describing the dosimetry at participating institutions. Representative data from the monitoring programs will be discussed and examples will be presented of specific instances in which the RPC contributed to the discovery and resolution of dosimetry errors.
The RPC is supported by PHS grants CA 10953 and CA 81647 awarded by NCI, DHHS

Educational Objectives:
1. Become familiar with the activities of the Radiological Physics Center.
2. Know how to contact the RPC for assistance or collaboration.
3. Understand the role of the RPC in monitoring institutions that participate in clinical trials.
4. Review common errors and misconceptions regarding dosimetry, credentialing requirements, and other issues.

Imaging Scientific Session Room 609
Ultrasound Imaging

TH-C-I-609-01
Techniques to Monitor Transgenic Mouse Models of Prostate Cancer Using Ultrasound Micro-Imaging

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Purpose: The usefulness of three-dimensional (3D) high-frequency ultrasound as a tool to monitor tumor progression in a genetically engineered mouse model of prostate cancer was investigated. **Method and Materials:** A genetically engineered mouse model (PSP94 gene-directed transgenic mouse adenocarcinoma of the prostate) was used that spontaneously developed prostate tumors. Mice were imaged with a commercial high-frequency ultrasound system including 3D imaging, power Doppler, and 3D power Doppler capabilities. Primary and metastatic tumor detection was confirmed by gross pathology and histology. Primary tumors were imaged longitudinally to monitor growth. Power Doppler was used to investigate blood vessel formation within tumors. **Results:** Primary tumors could be detected while still small (under 2.5 mm in diameter) and imaged repeatedly as they grew. Tumors were manually segmented in 3D images to measure volumes. Exponential growth curves fit the measured tumor volumes well (r^2=0.939 to 0.986) even though the estimated growth rate constants (0.054 to 0.143 $days^{-1}$) were markedly different. Examples of metastatic tumors were also detected, including a liver and a lymph node metastasis. Initial 3D power Doppler reconstructions showed intratumor vessels approximately 150 □m in diameter. **Conclusion:** High-frequency ultrasound can be used for longitudinal studies of volume and vasculature development of prostate tumors in genetically engineered mice. Ultrasound is a promising technique for assessing treatment responses in preclinical trials of prostate cancer therapies. **Conflict of Interest:** VisualSonics, the manufacturer of the ultrasound system, has licensed 3D reconstruction, visualization, and segmentation software from our laboratory.

TH-C-I-609-02
Refill Curve Simulations of Rabbit Kidney and of Liver with VX2 Carcinoma

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Purpose: A flow simulation model (Potdevin et al, 2004) has been adapted for use in vascular structures with varying transit characteristics. The highly structured nature of the kidney tissues were taken into account in the modified simulations and the resulting contrast transit modeled for the case of in-plane destruction followed by imaging of contrast refill. In the liver, the systemic and portal systems are being modeled as well as potential RE uptake of contrast agent and pooling due to leakage of cancerous vasculature. **Method and Materials:** For initial comparisons, real-time refill curves were acquired from rabbit kidneys using the contrast agent Definity (Bristol-Myers Squibb Company,New York,NY). A similar study was then developed for rabbit livers in which VX2 carcinoma was implanted for a varying time of 7 to 22 days. Two tissue classification images were generated: one using the exponential fit method with a Bayesian discrimination, another using the simulated refill curves and a simple RMS error computation. **Results:** These initial investigations showed a good correlation between identified medullary and cortical tissues and automated segmentation based on simulations results. Furthermore, the simulations helped reveal information in the refill curves beyond the time constant of a simple exponential fit. Initial analysis of liver images shows differences in transit time behavior at the location of implanted tumors. **Conclusion:** The tissue segmentation using either technique matches what is expected of a kidney, with a better discrimination between the medulla and the cortex observed when using the simulations that account for transit characteristics of vascular structures.
We hope to determine whether normal and abnormal liver tissues will be classified using these techniques. The best results were obtained in later phase cancer.

TH-C-I-609-03
3D Prostate Model Reconstruction From 2D Transrectal Ultrasound Biopsy Images

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Purpose: Biopsy of the prostate using 2D transrectal ultrasound (TRUS) guidance is the current gold standard for diagnosis of prostate cancer. Physicians' procedural accuracy and precision is limited by working within the current 2D biopsy environment that is susceptible to uncertainties when targeting 3D biopsy locations, which can ultimately result in false patient diagnoses. We propose a technique for the reconstruction of a patient-specific 3D prostate volume from a sparse collection of 2D US biopsy images that may be utilized for intra-biopsy needle guidance and accurate prostate volume calculation. **Method and Materials:** 2D TRUS axial and sagittal biopsy images, with known 3D coordinates, were simulated from 3D US prostate image volumes acquired from biopsy patients. The prostate boundaries were manually outlined from each simulated biopsy image and radial basis functions were used to estimate the 3D prostate capsule from collections of 2D boundary outlines varying from 6-16 contours. Each reconstructed prostate model was compared to a manually segmented, 3D planimetry model for volume and surface boundary accuracy as well as the clinical-standard prolate ellipsoid volume estimation technique. **Results:** Prostate models reconstructed from simulated biopsy images ranging from 8 – 16 contours demonstrated a consistent volume error range of 1.3% - 0.38%, which was less than the clinical standard calculation that produced a 1.44% error. The mean prostate surface boundary error for all generated models was consistently < 1 mm with a RMS ~= 1.1 mm. **Conclusion:** We have demonstrated a reconstruction technique capable of generating a 3D prostate model from a small sample of 2D TRUS biopsy images. Initial results suggest the fidelity of this reconstruction technique for generation of prostate models with accurate capsule surface contours and volume measurements, making it a potential tool for 3D intra-biopsy needle guidance and more accurate prostate volume calculations.

TH-C-I-609-04
A Quick and Accurate Calibration Method for 3D Ultrasound in Image-Guided Radiotherapy

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Purpose: To develop a quick, accurate and user-independent method for calibrating a freehand 3D ultrasound system to CT-Sim and/or linac room coordinate systems. **Method and Materials:** A 3D ultrasound system (Restitu, Resonant Medical Inc) designed to be used in both CT-Sim and radiotherapy treatment rooms is used. This system consists of a 2D ultrasound probe tracked by an optical tracker. An ultrasound phantom was developed which contains six embedded high-contrast rods at known locations. A removable top-plate was designed to hold the ultrasound probe in 7 slots with different positions/orientations relative to the rods. The user acquires one image per slot, thus obtaining 7 independent views of the 6 rods. The center of the rods are automatically detected in each ultrasound image. The algorithm calculates the optimal transformation between the detected and known rod positions. In this manner, the calibration from ultrasound image pixels to room laser coordinate system is determined. The transformation is appropriately scaled for different image depths. To evaluate the accuracy, a sphere embedded in the phantom was imaged and reconstructed into a 3D voxel image with the given calibration. The reconstructed center of the sphere was compared to its position derived from a CT scan of the same phantom . **Results:** The ultrasound calibration procedure is found to be accurate to within the CT sphere center measurement uncertainy. System calibration requires less than 5 minutes.

Conclusion: The present calibration method enables a very quick and accurate method of converting a series of 2D ultrasound images into a 3D voxel set in CT-Sim and/or treatment room coordinate systems. This forms the basis for accurate 3D ultrasound imaging in radiotherapy, both for improved organ definition for planning and image guidance in the treatment room. **Conflict of Interest:** The authors are employees of Resonant Medical Inc.

TH-C-I-609-05

Spatial Calibration of a Novel Real-Time Dynamic Ultrasound/CT Image Fuser

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Purpose: To increase interpretability of ultrasound and to measure respiratory motion. **Method and Materials:** An ultrasound probe is affixed to a position-sensing articulating arm, and the calculated ultrasound image plane is dynamically intersected with a 3D CT image volume. The resulting synchronized ultrasound/CT image pair is superimposed on a multi-layer display or blended on a single monitor for real-time presentation. Additionally the ultrasound stream is captured to file along with regularly sampled system transformations, and the ultrasound/CT image pairs can be extracted at a later time. The system is calibrated with derivations of the transformations among the coordinate systems of the patient, ultrasound probe, and articulating arm. The system was tested by capturing image pairs using a QA phantom, and calculating the proximity of registered points. Specifically, identifiable points were registered in the ultrasound image, and the transformations used in deriving the CT image plane were applied to those points. Distances were calculated between those transformed ultrasound points and the corresponding points in the CT image. **Results:** In 12 experiments, the mean distance between the transformed ultrasound points and the corresponding CT ranged from 1.13 mm to 1.80 mm, with standard deviation between 0.81 mm and 1.76 mm, and maximum distance between 4.56 mm and 12.08 mm. The results were not consistently affected by the position or orientation of the phantom with respect to the articulating arm, nor by the depth of the image plane. **Conclusion:** The system provides real-time and post-imaging super position of ultrasound and CT images, with displayed accuracy better than 2 mm. The high resolution of the CT image provides accurate context for interpreting the ultrasound. Moreover, it provides a static reference for observing and calculating the effect of respiratory motion and other real-time factors on patient anatomy. Work is funded by NIH grant 1RO1EB002899.

TH-C-I-609-06

Freehand Scan Ultrasound Reconstruction Based On Optimal 3D Grid Selection and Anisotropic Diffusion Interpolation

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Purpose: presents a new algorithm for the reconstruction of the volume of human organ from multiple B-scans and the associated image plane position and orientation measurements as acquired by hand scanning across the surface of the human body with a probe attached to a a Microcribe articulating arm. **Method and Materials:** The 3D reconstruction grid is optimized using an optimal method. A cost function is built for this problem as to minimize the registration errors between the scan planes and the reconstruction 3D grid while allowing for the largest possible voxel size. With the 3D grid defined, every B-mode scan is inserted into the grid. An anisotropic diffusion-based interpolation supported by the gradient vector flow is developed for empty voxel filling. **Results:** We tested 'griddata3' in the MATLAB™ for voxel nearest neighbor interpolation which is based on a Delaunay triangulation of the data. The out-of-memory problems prevented our 2 GB memory computer to run properly when the number of scans is large and/or full-resolution reconstruction is attempted. Several freehand US sweeps of a prostate phantom has been used to test the proposed reconstruction method yielding appealing visual results without having the out-of-memory problem any more. **Conclusion:** Freehand 3-D US reconstruction generates a geometrically-registered 3-D volume of an organ out of multiple B-mode images acquired at irregular positions and from arbitrary view angles by inserting each 2-D image into a uniform 3-D grid using the position and orientation measurements of the scan plane. Depending on the voxel size, empty voxels may exist in the 3-D grid. To handle this problem of holes, a 3D Interpolation is needed which usually demands heavy computation and huge computer memory. The proposed diffusion-based reconstruction algorithm is computation-efficient and less memory sensitive for 3D US reconstruction.

TH-C-I-609-07

Multi-Resolution Rigid Registration of Ultrasound and CT Based On Similarity Measures

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Purpose: In radiation therapy, registration of real-time ultrasound (US) images to CT/MR images is valuable in reducing patient setup errors. Any registration process starts with rigid registration. At present practice this often is done manually by visual inspection. This study investigates the use of similarity measures as the basis of US to CT registration. This approach is potentially faster and less prone to errors compared to segmentation or landmarks based approaches. **Method and Materials:** A special phantom with objects visible in both CT and US was constructed and imaged. 3D-US images were obtained using a 2D probe attached to a mechanical translator. US and CT datasets were co-registered using an iterative registration algorithm that includes: an interpolator, a similarity metric and an optimizer all working at multiple resolution. The fitness of a similarity metric to the registration task was studied by translational and rotational perturbations of rigid transforms to compute functional trends of a similarity score versus deviation. Metrics, if effective, should guide the optimizer back to the true position. A multi-resolution technique was employed to improve speed. Resolution degradation is guided by voxel sizes of both modalities toward isotropic resolution. A general purpose optimizer, Simplex, was used along with the nearest neighbor interpolation method. **Results:** The Simplex optimizer demonstrated feasibility but not speed. In evaluating similarity metrics, square differences expectedly failed in this multi-modality registration, while mutual information (MI) and cross correlation (CC) were reasonable. Randomly rigid perturbations of up to $^{+}$/-10mm translations and +/-5^{o} rotations from the true position converged to a visually accurate position within clinically acceptable limits of 1.0mm shifts and 1.0^{o} rotations. **Conclusion:** Similarity based registration using CC or MI is feasible and effective even on raw US/CT images. Future improvement will include image filtering, adding a weighting bias, or selecting a better optimizer.

TH-C-I-609-08

Ultrasound Transducer Performance Evaluation With An Electronic Probe Tester

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Purpose: Ultrasound transducer performance plays a major role in the integrity of B-mode mages and in image quality. A frequent problem with arrays is "element drop out," caused by electronic or mechanical interruption of signals. Currently this is detected using visual inspection of images of patients and or phantoms. Our objectives were to evaluate an electronic probe tester for determining functionality of array transducers and to compare results of the tester with subjective analysis of images of uniform phantoms. **Method and Materials:** A FirstCall 2000 (Sonora Medical Systems) electronic transducer tester was used on array transducers. The device exercises each element in the array, measuring its capacitance, pulse-echo sensitivity, pulse width, center frequency and bandwidth using planar targets. Probe adapters and software enable the FirstCall to utilize connection configurations of different transducer manufacturers. Probes from Siemens Sequoia and Philips HDI 5000 machines available in the UW Hospital were tested. Images of a uniform phantom were obtained from each transducer using sensitivity and gain settings for uniform gray scale. The images were examined for evidence of element dropout. **Results:** Of twenty-one probes initially tested, nine exhibited some level of malfunction (>2 "dead" elements). Of the nine, four exhibited a significant level of malfunction (>5 dead elements). Probes that had only a few dead elements showed no signs of image degradation in the phantom tests. When multiple (~5 or more) elements are dead, manifestations of the problem appeared in the phantom images. **Conclusion:** The FirstCall provides an objective test of transducer performance, with greater sensitivity than a phantom test. The penalty for using a probe with only a few dead elements may seem minimal if no indication is seen in a uniform phantom image. A clinically applicable

threshold for determining whether a transducer is suitable for use still needs to be established.

TH-C-I-609-09

Quantifying Breast Density for Improved Evaluation of Breast Cancer Risk

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Purpose: To quantify a preliminary relationship between breast density and acoustic velocity using ultrasound computed tomography. The existence of such a relationship may provide quantitative prognostic information that can be used to determine breast cancer risk. **Method and Materials:** A sample of female patients was imaged using the CURE, or Computerized Ultrasound Risk Evaluation, device. The mammographic densities of each patient were assigned by a certified radiologist on a 1 (fatty) to 4 (dense) scale. Regions of interest (160 mm^2) were selected contralateral to present anomalies in multiple adjacent slices centrally located on the breast, away from the chest wall and nipple regions. The minimum, maximum, mean, and standard deviation of the acoustic velocity were recorded for each slice. **Results:** This statistical information was then correlated against breast density to investigate the presence of meaningful relationships. Initial assessment of this sample suggests that the maximum sound speed values increase with increasing mammographic density, while the minimum values appear to decrease with increasing density. The mean sound speed shows a weak but steady trend with increasing density. The behavior of these correlations suggests that the intrinsic scatter of sound speeds within the breast tissue is a strong function of the mammographic breast density. However, these relationships are statistically weak due to a small sample size, and further investigation will be required to strengthen this association.

Conclusion: This preliminary examination suggests that a quantifiable relationship between breast density and sound speed may exist. If these results are further validated in larger studies, then it may be possible to utilize CURE measurements to assess breast cancer risk with a quantitative score. Results will be available for forty additional patients in July, and a more definitive conclusion regarding these findings can then be provided.

TH-C-I-609-10

Computerized Classification of Non-Biopsied Lesions Seen On Breast Ultrasound

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Purpose: To investigate the performance of a computerized lesion classification scheme in a realistic testing protocol resembling clinical practice. Computerized classification of breast lesions has generally been tested on lesions of biopsy-proven pathology. In that fashion, the known pathology serves as the truth in the performance evaluation of the computer. In practice, however, many patients are never sent to biopsy because their lesions are deemed to be most likely benign. In order for a computerized classification scheme to be useful and its results believable to the radiologists, it needs to be able to classify those lesions correctly. **Method and Materials:** We investigated the performance of our computerized lesion segmentation and classification scheme. There were 42 images of 11 cancerous lesions, 114 images of 30 biopsy-proven benign lesions (including both cystic and solid lesions), and 243 images of 57 lesions that to date have not been sent to biopsy (including suspected cysts, benign solid lesions, and other benign breast disease).

The computer was trained on the biopsy-proven set and we performed stepwise feature selection to obtain a 4-feature subset that best distinguished malignant from biopsy-proven benign lesions. The computer scheme was tested on the non-biopsy cases, and the ability to distinguish these from the cancers in the training set was assessed. **Results:** The area under the ROC curve (A_z value) was 0.96 for the training of the scheme on biopsy-proven pathologies in the distinction between cancers and benign lesions. The A_z value was 0.93 for testing in the distinction between cancers and non-biopsy-proven benign lesions. **Conclusion:** Our computerized classification scheme shows promising performance in a testing protocol that is more representative of its intended use in clinical practice than the typical testing on lesions with biopsy-proven pathology only.

COI: grants: USPHS and U.S. Army. Shareholder: R2 Technology (last author)

Imaging Scientific Session Room 611

Advances in X-ray Radiography and Fluoroscopy

TH-C-I-611-01

Establishing Urinary Stone Composition Nondestructively Using X-Ray Coherent Scatter: A Novel Technique with Potential Clinical Applications

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Purpose: Current kidney stone analysis techniques are limited in their abilities to simultaneously characterize composition and structure. Laboratory techniques like infrared spectroscopy (IRS) likely miss vital components as they require small powdered samples for analysis. We investigate the application of x-ray coherent scatter (CS) based analysis to identify topographic urinary stone composition non-destructively, ex vivo. CS is dependent on molecular structure and can therefore distinguish different compounds. The use of diagnostic x-ray equipment facilitates examination of structural arrangements of minerals within intact calculi. **Method and Materials:** Tomographic images of CS properties of a stone-mimicking phantom, containing common stone components were acquired with a purpose-built scanner. These were analyzed to assess the accuracy of CS analysis when applied to urinary calculi. The composition of intact human urinary calculi was then examined by CS and compared to the clinical gold standard, IRS. **Results:** Composition maps of the phantom generated from CS patterns, demonstrate that stone components can be accurately separated in the presence of many different chemicals. Similar maps from intact stones revealed the spatial arrangement of constituent minerals. Primary stone components were identified by both CS and IRS. However, less prevalent secondary components were missed by IRS in some instances. Composition as determined by CS analysis is thus shown to generate scatter cross sections that match the features of stone cross sections better than IRS-determined composition. **Conclusion:** Coherent scatter from diagnostic x rays can be used to identify structure and composition in urinary calculi non-destructively. This can provide substantially more clinically-relevant information than currently available from IRS. The CS-derived composition images presented here support the development of CS analysis as a means for identifying stone composition characteristics both at the laboratory level, for post-operative analyses and explorations of responses to therapy, and possibly for in situ composition assessments.

TH-C-I-611-02

Exposure Rate Limitations for Light Image Intensifiers with Microchannel Plate Amplifiers Used in a Micro-Angiographic Fluoroscope

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Purpose: The region-of-interest micro-angiographic fluoroscope (MAF) enables both high-resolution rapid-sequence micro-angiography and fluoroscopy. The critical component is the micro-channel plate (MCP)-based light image intensifier (LII). The effect on maximum detector entrance exposure rate caused by LII nominal working-range limitations will be investigated. **Method and Materials:** The prototype MAF we built consists of a 350 micron thick columnar CsI(Tl) scintillator coupled by a 2:1 fiber-optical taper to an 18mm diameter variable gain LII with two-stage MCP optically viewed by a 12-bit, 1024x1024, 30fps CCD camera. Pixel value versus exposure (0–870μR) was measured with a LII gain of $492(W/m^2)_{out}/(W/m^2)_{in}$ at two different exposure times: 6ms and 30ms. A calculation was made of the maximum entrance MAF exposure rate that results in the maximum LII phosphor screen luminance. The linearity of the MAF was also measured with a higher LII gain of $7{,}728(W/m^2)_{out}/(W/m^2)_{in}$ and a lower lens collection efficiency at an exposure time of 30ms to show the effect of limitations in the LII nominal working range. **Results:** The MAF with a LII gain of $492(W/m^2)_{out}/(W/m^2)_{in}$ demonstrated linear behavior with 30ms exposure times when the maximum exposure rate was 29μR/ms; however, large

fluctuations of mean pixel values occurred for 6ms when the exposure rate exceeded 30μR/ms. The calculation at maximum luminance predicted a maximum entrance detector exposure rate of 32.6μR/ms. The MAF used at a higher LII gain of 7728$(W/m^2)_{out}/(W/m^2)_{in}$ demonstrated a non-linear behavior and average pixel value fluctuations in the exposure range 81-870μR. **Conclusion:** LII working range limits must be considered in the design of the MAF. The measured instability occurred for exposure rates above the value calculated to result in maximum LII luminance. Higher lens collection efficiency can enable the use of a lower LII gain and increased entrance MAF exposure rate.

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TH-C-I-611-03

Three-Dimensional Reconstruction of An Asymmetric Vessel Phantom Using Two X-Ray Projections

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Purpose: Vascular lumen shape often predicts potential lumen occlusion and inadequate blood supply. Three-dimensional (3D) lumen information can facilitate diagnosis and interventional therapies. We present a technique for 3D reconstruction of asymmetric vessel lumens using two x-ray projections. **Method and Materials:** Images were acquired of a contrast-filled vessel phantom with an asymmetric lesion. For two-view reconstruction, lumen diameters, lesion geometric characteristics in each view, and correspondence between views were determined using previously described methods. Intensity profiles across the vessel lumen were extracted along epipolar lines. The profiles were fit using an elliptical model, and the deviation from ellipticity was taken to correspond to intruding plaque. The fitted profiles from the two views were used to generate elliptical cross sections, and the plaque information was used to deform these cross sections asymmetrically. The 3D lumen was created by combining individual 2D cross sections along the vessel length. To verify the method, 3D reconstructions were obtained in two ways from a set of digital subtraction angiography (DSA) images of the phantom obtained using a high-resolution microangiographic detector (43 micron pixels): (a) using two orthogonal projections and our two-view method, and (b) using 180 projections and a Feldkamp algorithm. The two reconstructed lumens were superimposed and the root-mean-square (RMS) distance between the lumen boundaries and percent overlap of the lumen volumes were calculated. **Results:** The RMS distance between the boundaries of the two-view and the micro-CT reconstructed lumens was less than 0.2 mm over the entire length of the vessel which had a diameter of 3.6 mm in non-lesion segments; the volume overlap was 94%. **Conclusion:** Accurate 3D reconstruction of an asymmetrically stenosed vessel lumen was obtained using two radiographic projections as verified by comparison with microangiographic cone-beam CT reconstruction.

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Experimental Validation of An Angiographic Method for Determining Coronary Fractional Flow Reserve

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Purpose: To investigate an angiographic technique for determining fractional flow reserve (FFR) for assessing anatomic and physiologic significance of intermediate coronary stenoses from routine coronary arteriography. **Method and Materials:** A swine animal model was used to investigate an angiographic method for determining FFR for different severity stenoses. The proximal portion of the left anterior descending (LAD) artery was dissected free from the epicardium. An ultrasonic transit-time flow probe was implanted distal to the left main coronary artery bifurcation. A vascular occluder was positioned distal to the flow probe to apply different levels of stenoses. Acquired angiograms were corrected for scatter-veiling glare and pincushion distortion. Coronary arterial flow and lumen volume were determined angiographically from a first-pass distribution analysis. A computer simulation utilizing a fully reconstructed swine coronary arterial system was used to study the coronary arterial flow-volume relation. Results from this simulation study were used to determine hypothetical normal flows from measured arterial lumen volumes. Angiographic FFR was calculated from the ratio of the measured hyperemic flow to the hypothetic normal flow derived from the arterial lumen volume and compared to FFR measured directly with the flow probe. **Results:** Simulation studies showed that coronary flow (Q) was related to cumulative lumen volume (V) through a power-law relation. For vessels detectable by coronary angiography (>0.1 cm^3), a linear relationship was observed between coronary flow and lumen volume (Q= 5.2+45V; R=0.992). Experimental validation of this flow-volume relation showed similar results (Q= -0.503+52.4V, R=0.997). A comparison between FFR measured with angiography and with the flow probe showed good correlation (r>0.9). **Conclusion:** Regional coronary flow can be determined with angiography, and normal regional flow without the presence of stenosis can be calculated using flow normalized to arterial lumen volume. Thus FFR can be calculated from the same images obtained from routine coronary arteriography.

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Quantification of Coronary Artery Calcium Using Real Time Dual Energy Subtraction Based On a Flat Panel Detector

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Purpose: To evaluate the feasibility of a real time dual-energy subtraction technique with dynamic filtration based on a flat panel detector for quantifying coronary arterial calcium. **Method and Materials:** In this dual-energy subtraction technique, the beam energy and filtration were switched at 30 Hz between 60 kVp and 120 kVp + 0.8 mm additional silver filtration. The calcium contrast and contrast-to-noise ratio (CNR) were measured using a Lucide step phantom and a 3 mm thick bone equivalent material. The performance of the dynamic filtration technique was compared with a static filtration technique (4 mm Al + 0.2 mm Cu for both beams). Arterial vessel phantoms with calcium aerial densities in the range of 30-140 mg/cm^2 and a total calcium mass of 8-92 mg were imaged over a Lucite step phantom. The low and high energy images were corrected for scatter before subtraction. The total calcium mass was measured using a densitometry technique. The entrance exposure was measured and effective dose was estimated. **Results:** The dynamic filtration technique produced 60% higher calcium CNR and required 25% higher x-ray tube loading as compared to the static filtration technique. A calcium aerial density of approximately 30 mg/cm^2 was detectable. The known (K) and measured (M) calcium mass were related by M=0.97K+0.028 (R=1.0). The calcium measurement precision was 4 mg, determined from 10 repeated dual energy images. The entrance exposure and effective dose were 7 mR and 5.2 μSv for each dual energy image, respectively. **Conclusion:** Dual-energy subtraction can be a potentially useful technique for the quantification of coronary arterial calcium and provide a noninvasive technique for diagnosis of coronary artery disease.

TH-C-I-611-06

MTF(f), NPS(f) and DQE(f) of An X-Ray Imaging System Based On a Photon Counting MCP Detector

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Purpose: To evaluate inherent MTF(f), NPS(f) and DQE(f) of a prototype x-ray imaging system with photon counting microchannel plate (MCP) detector. **Method and Materials:** The MCP detector was used in edge illumination mode as a linear array x-ray detector in scanning slit image acquisition geometry. The detector FOV was 60 mm. MCPs with 63 mm length, 25 μm channel diameter and 5 μm channel wall thickness were used. The slit width was 0.25 mm. Delay line position encoding electronics was used. Images were acquired using an x-ray tube with 0.4 mm nominal focal spot size at 40 and 90 kVp using an SID of 50 cm and a magnification 1.1. MTF was measured using edge spread function method. NPS was calculated using flat field corrected flood images. DQE was calculated from MTF, NPS and using both measured and Monte Carlo calculated QE. **Results:** For 25 μm channel MCP, 50% MTF was achieved at 6 lp/mm and 4 lp/mm for 40 and 90 kVp tube voltages, respectively. The highest visualized frequency was 11 lp/mm at 40 kVp. NPS was shown to be frequency independent. QE measured at 90 kVp was 56% and 70% for 25 μm and 5 μm channel MCPs, respectively. Calculated QE was 64%, 86% and 92% for 25, 5 and 2 μm channel MCPs, at 90 kVp. The above QE

values represent the DQE(0). The MTF(f) curves normalized by QE represent DQE(f) due to frequency independent nature of the NPS. **Conclusion:** MCP detector has shown adequate MTF(f) and DQE(f) for potential application in medical imaging. This is in addition to its inherently high count rate and scatter rejection feature of the scanning slit system. Combination of these capabilities in the photon counting system would allow for significant decrease in patient dose.

TH-C-I-611-07

Quantum Efficiency of An MCP Detector: Monte Carlo Calculation

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Purpose: To calculate quantum efficiency (QE) of the microchannel plate (MCP) detector at different x-ray tube voltages using Monte Carlo method. **Method and Materials:** Monte Carlo calculation of the QE was performed using GEANT4. The MCPs with channel diameters of 2-25 μm and lead contents of 50%, 38%, 20%, 8% and 0% were considered. QE calculations were performed using GEANT4 for monochromatic photons at 200 energy points in the 0-200 keV range with 1 keV steps. QE of MCP was calculated for 35, 45, 90, and 120 kVp photon beams from tungsten target x-ray tube, passed through corresponding soft tissue equivalent filters. QE for polychromatic photon beams were calculated by weighting the monochromatic QE with the photon energy distribution of the filtered x-ray spectra. **Results:** The QE for 35 kVp beam was 83% and 86% for MCPs with 2 μm channel diameter and 50% lead content, and 5 μm channel MCP with no lead in the material, respectively. Efficiency was decreased to 51% at 35 kVp for MCP with 50% lead content and 5 μm channel diameter. The efficiencies for 45 kVp photon beams were 68% and 76% for MCPs with 50% lead and no lead, respectively, and 5 μm channel diameter. QE was increased at 45 kVp to 91% for 2 μm channel MCP with 50% lead. The QE of the 90 kVp and 120 kVp beams were in the 81-92% ranges except the lead free MCP, for which it was decreased to 20-30%. **Conclusion:** Monte Carlo calculations of the quantum efficiency of the edge on MCP detector shown that the smaller the MCP channel diameter, the higher the QE. Commercially available MCPs with 5-6 μm channel diameters can provide sufficiently high quantum efficiency for medical x-ray imaging applications.

TH-C-I-611-08

A New Concept of Indirect Flat-Panel Detector with Avalanche Gain: SAPHIRE (Scitillator Avalanche Photoconductor with High Resolution Emitter Readout)

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Purpose: To investigate the feasibility of a new concept of indirect flat-panel detector with avalanche gain and field emitter array (FEA) readout to improve the imaging performance at low dose with high resolution. **Method and Materials:** The proposed detector is made by optically coupling a structured scintillator (CsI) to a uniform layer of avalanche amorphous selenium (a-Se) photoconductor called HARP (High Avalanche Rushing amorphous Photoconductor). The HARP layer absorbs the visible photons emitted from the scintillator and generates electron-hole pairs. These carriers undergo avalanche multiplication under a sufficiently high electric field E_{Se} and form an amplified charge image. A two-dimensional FEA, which is essentially a flat electron source, is proposed as a new method to read out the charge image. The proposed detector is called SAPHIRE (Scintillator Avalanche Photoconductor with HIgh Resolution Emitter readout). Experimental and theoretical methods were developed to study the factors affecting the x-ray response and spatial resolution of SAPHIRE. **Results:** The avalanche gain in the HARP layer depends on both its thickness and E_{Se}. The avalanche gain for an 8-μm-thick HARP layer is 46 under an E_{Se} of 110V/μm. The gain can be turned off in high dose applications (e.g. radiography) by decreasing the E_{Se}. Our electron optics simulation of SAPHIRE shows the dominant source of blur is the lateral spread of the electron beams from the FEA, which depends on the geometry and bias potentials of different electrodes in the detector. With proper electron optics design a pixel size of 50 microns is achievable. **Conclusion:** The avalanche gain of SAPHIRE can provide x-ray quantum noise limited images down to a single x-ray photon. The gain is programmable by changing E_{Se}, which ensures wide dynamic range for SAPHIRE. The FEA can potentially provide a smaller pixel size and higher readout speed than existing flat-panel detectors.

TH-C-I-611-09

Development of Direct Detection Active Matrix Flat-Panel Imagers Employing Mercuric Iodide for Diagnostic Imaging

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Purpose: To characterize the performance of prototype direct-detection active matrix flat-panel imagers (AMFPIs) employing recently improved forms of polycrystalline mercuric iodide photoconductors as x-ray converters for fluoroscopic imaging. **Method and Materials:** While direct and indirect detection flat-panel imagers offer good performance for many applications, their modest signal per interacting x-ray limits the DQE performance under imaging conditions of low exposure such as in fluoroscopy. One possible pathway to overcome this limitation involves the use of a high gain photoconductive x-ray converter such as mercuric iodide (HgI_2). Accordingly, performance results from a number of AMFPI prototypes employing two types of polycrystalline HgI_2 (a form created through physical vapor deposition, PVD, and a particle-in-binder form involving screen printing, PIB) are reported. Each prototype incorporates an array with a pixel format of 768x768 and a pixel pitch of 127 μm, and was operated under fluoroscopic conditions. The measured performance was compared to theoretical calculations based on a cascaded systems model. **Results:** Performance of the prototypes is reported in terms of pixel properties as well as MTF, NPS and DQE. Recent significant improvements in the properties of HgI_2 photoconductors, such as chemical stability, low dark current (< 10 pA/mm^2), low lag, and high x-ray sensitivity (corresponding to an effective ionization energy approaching the theoretical limit of ~5 eV) resulted in a high DQE performance at low exposures. Pixel-to-pixel non-uniformities, which tend to reduce the dynamic range, remain high (~10% to 30%) and thus require further optimization. **Conclusions:** While the development of polycrystalline HgI_2 as an x-ray converter for AMFPIs has achieved important milestones related to various material properties, various challenges remain. Nevertheless, the high x-ray sensitivity and DQE observed at low exposures demonstrate the potential for input-quantum-limited fluoroscopic operation. This work was supported by NIH grant R01-EB000558.

Joint Imaging/Therapy Scientific Session Room 6B
Image-Guided Localization and Intervention

TH-C-J-6B-01

Guided Surgery Using Rapid Prototyping Patient Specific Guides

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Purpose: One of the basic tenets of Neurosurgical planning is the ability to generate an operative approach that minimizes the disruption of normal tissues while allowing the required access to target tissues. To aid the surgeon in his or her ability to appreciate the location of target tissues, as well as the relationship of the target to normal tissues, graphical workstation have been employed. The introduction of Image Guidance Systems (IGS) into OR has brought along a host of new computers, infrared camera systems and radio frequency transmitters and receivers, all of which pose restrictions on the placement and operation of the other equipment needed for the operative procedure. In order to provide the advantages of IGS while avoiding the problems associated with the commercial equipment we elected to investigate a mechanical alternative, one that did not require any of the above equipment to be present with the operating room.

Method and Materials: Recently, a new generation of 3-dimensional printers has been developed. These systems are capable of fabricating OR compatible objects within an hour of design. The goal of this project is to develop software that provides the surgeon with the ability to build a patient specific 3D model from a diagnostic image dataset and to then plan a surgical procedure. Utilizing the 3D patient specific model, the software designs a patient specific reference frame and fabricates the frame using rapid prototyping technology. This reference frame incorporate all necessary trajectories, including mechanical referencing to the patient,

guidance for initial skin incision, trajectory alignment to the target tissues, as well as providing a mechanical platform for mounting other surgical tools. **Results Conclusion:** We have written and tested this new generation of software on phantom targets and are now engaged in an IRB surgical trial assessing the system's accuracy and precision.

TH-C-J-6B-02

Towards Intra-Operative Dosimetry in Prostate Brachytherapy

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Purpose: Intra-operative dosimetric optimization of TRUS-guided prostate brachytherapy implants requires localization of seeds relative to prostate [1]. Analytical tools are available to intra-operatively tailor an implant-plan, thereby accounting for inevitable deviations [2]. **Method and Materials:** The majority of the practitioners have C-arm fluoroscopes in the treatment room, making intra-operative dosimetry feasible with little additional cost. The obstacles towards intra-operative dosimetry are: (a) discerning the 3D poses of fluoro images, (b) registering fluoroscopy to TRUS, and (c) establish seed correspondences in multiple fluoro images. We address the first two issues by single-image-based fluoroscope tracking (FTRAC) fiducial with salient attributes: small dimensions (*3x3x5cm*); need not be close to the anatomy of interest; auto-segmentable; and mathematically robust to segmentation, calibration, and image distortion errors. The 3D coordinates of the segmented seeds are calculated upon resolving the correspondence of seeds in the multiple X-ray images, achieved by an algorithm called MARSHAL. We formalize seed-matching as a network flow problem, which has salient features: (a) extensively studied exact solutions, (b) performance claims on the space-time complexity, (c) optimality bounds on the final solution. **Results:** The FTRAC fiducial tracks a C-arm to an accuracy of *0.56mm* in translation and *0.33°* in orientation, comparable to commercial tracking systems. On pre-segmented images, MARSHAL achieved 100% correct matching in simulation experiments. In experiments on a precision-machined phantom, the FTRAC and MARSHAL correctly matched and reconstructed 98.5% of the seeds with a mean 3D accuracy of 0.63*mm*, while the mean error for the mismatched 1.5% of seeds was only 0.91*mm*. **Conclusion:** Performance of FTRAC and MARSHAL appear to be adequate for intra-operative dosimetry in brachytherapy.

[1] Nag et al. Int J Radiat Oncol Biol Phys 51(5):1422-30
[2] Todor et al. Phys Med Biol 48(9):1153-71

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Keywords: Radiation Planning, Prostate Brachytherapy, Seed Matching, C-arm Tracking, Registration.

TH-C-J-6B-03

Electron Beam Treatment Verification Using Measured and Monte Carlo Predicted Portal Images

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Purpose: In this study, we propose to use the bremsstrahlung part of the electron beam to produce portal images during electron beam treatments. We also investigate the possibility of using Monte Carlo (MC) simulations to predict the electron beam portal images and to use these predicted images to verify electron beam treatment delivery. **Method and Materials:** The Varian CL21EX linear accelerator and the aS500 Varian electronic portal imaging device (EPID) were used to acquire all images. The images were obtained for various electron energies (6 to 16 MeV) and cut-out sizes; a 10.7 MU dose was delivered during the acquisition. A portal imaging quality assurance phantom (QC-3V) was used to calculate the contrast, the resolution and the modulation transfer function (MTF) of the images. Images were also acquired using Rando, an anthropomorphic phantom. EGSnrc was used to build a MC model of the Varian CL21EX and of the aS500 EPID. MC calculations were used to characterize the bremsstrahlung photon beam and to obtain predicted images of the QC-3V and Rando phantom. **Results:** The contrast and the resolution of the images obtained with the bremsstrahlung radiation are comparable to those of a 6 MV photon beam. MC simulations showed that the main sources of photons in an electron beam are the scattering foils and the applicator. It was also shown that the quantity and the quality of the bremsstrahlung beam produced have a direct impact on the image quality. The simulated and measured portal images agree within ± 8% for both the QC-3V and the Rando phantom. **Conclusion:** Images with adequate contrast and resolution were obtained under various relative conditions. Portal images were predicted using MC simulations and a good agreement was obtained; this is a first step towards an electron treatment verification tool.

TH-C-J-6B-04

Performance Characterization of Megavoltage CT Imaging On a Helical Tomotherapy Unit

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Purpose: This study characterizes the image performance of the megavoltage computed tomography (MVCT) imaging from the Hi-ART II tomotherapy treatment unit using measures of noise, uniformity, contrast, linearity, and spatial resolution as a function of absorbed dose. **Method and Materials:** MVCT image performance was characterized using a AAPM CT Performance Phantom. The following tests were performed as a function of collimator pitch and image pixel size: image noise, spatial uniformity, objective (modulation transfer function) and subjective (hole patterns) spatial resolution, contrast linearity, and contrast-detail resolution. The multiple scan average dose (MSAD) was determined in a 20 cm diameter cylindrical phantom as a function of collimator pitch, and the beam energy was estimated from percent depth dose measurements. **Results:** The uniformity and spatial resolution of MVCT images generated by the HI-ART II are comparable to that of diagnostic CT images. The MVCT scan contrast is linear with respect to electron density of target material. MVCT images do not have the same performance characteristics as state-of-the-art diagnostic images based on objective measures of noise and low-contrast resolution, but large object low contrast resolution is sufficient to for identification of many important soft tissue structures. The MSAD ranges from 0.25 cGy to 1.1 cGy, and the effective beam energy is 3.5 MV. **Conclusion:** MVCT images from the Hi-ART II are adequate for verifying a patient's position at the time of radiation therapy. These images also provide sufficient contrast to delineate many soft-tissue structures. Hence, these images are adequate for reconstruction of the dose actually delivered to anatomical structures during radiotherapy. The dose delivered by the MVCT is low enough that images can be acquired on a daily basis.

TH-C-J-6B-05

Coordinate Transformation of KV Cone Beam CT Acquired with Prototype Flat Panel Mobile C-Arm for Patient Positioning Applications

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Purpose: A prototype mobile C-arm capable of kV cone beam CT has been proposed to evaluate patient setup accuracy. To facilitate this, the location of the C-arm's reconstructed image volume in the treatment room must be known. **Method and Materials:** A calibration procedure to make the necessary transformation between image coordinates and room coordinates has been developed using a commercial optical tracking system. Markers are placed on both the C-arm and a calibration phantom. After the initial calibration procedure, only the markers on the C-arm need to be located at the time of image acquisition to make the final transformation. The calibration procedure was evaluated using the optical tracking system and a phantom with attached reflective markers. After imaging, the markers were located in the reconstruction and then transformed into world coordinates. These positions were then compared to the markers location according to the tracking system (assumed true world coordinates). Movements were made to the C-arm, subsequent images acquired, and the analysis was repeated. Calibrations done on different days were also used to analyze the same data set. **Results:** The max error of any of the markers after the movements was below 1.4 mm, the mean absolute error below 0.9 mm, and the RMS error below 1.0 mm. The other calibrations had slightly larger errors but no marker out of any of the calibrations had a max error greater then 2.3 mm, a mean absolute error greater then 1.6 mm, or an RMS error greater then 1.6 mm. **Conclusion:**

The results show that using an optical tracking system can provide an accurate transformation of the reconstructed coordinates of a mobile C-arm into room coordinates.

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TH-C-J-6B-06

Using Portal Imaging and a Model-Based Estimation Algorithm to Correct for Intrafraction Prostate Motion

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Purpose: It is investigated how portal images from IMRT beams can be used to estimate intrafraction prostate motion when fiducial markers are implanted in the prostate and how these estimates can be used in adaptive radiation therapy. **Method and Materials:** The software framework ORBIT^{4}ART has been used to simulate intrafraction motion, marker positions and portal images (PI). The target motion is governed by a rigid body transformation. The following procedure estimates the position of the target before the delivery of each treatment beam. An image of the largest segment is recorded. The projection of transformed reference marker positions known from the planning CT are compared with the true marker positions in the PI. By minimizing the distance in the image plane between corresponding markers, the 3D rotation as well as the in-plane translation is estimated. ORBIT^{4}ART has also been used to perform dose registration in deformable tissue and to evaluate the effect of patient positioning on the delivered dose. In the tests the patient was repositioned based on the target position estimate acquired before the delivery of each beam. **Results:** The target registration error (TRE) is approximately as large as the unknown out-of-plane translation. If the target does not move between images the TRE is improved further since more information is added for every new PI. If couch corrections are made according to the estimates provided by the method, the delivered dose is in better agreement with the planned dose than if no such adjustments are made. **Conclusion:** The algorithm can be used to monitor intrafraction target motion. Although the estimated target translation lacks the out-of-plane component, online couch translations reduces the discrepancy between delivered and planned dose. **Conflict of Interest:** All authors are employees of the submitting company and own stocks or stock options.

TH-C-J-6B-07

Intra-Fractional and Inter/Intra-Field Organ Motion and a Proposal for a New Patient Set-Up Protocol

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Purpose: Current set-up protocols for prostate patients with gold markers receiving EBRT use orthogonal portal images acquired prior to treatment to position the patient. Times between image acquisition and treatment delivery for different gantry angles range from one to seven minutes, even longer for IMRT. During this time the prostate can shift from its corrected position. **Method and Materials:** An a-Si flat panel EPID was used to acquire pre-treatment portal images for positioning purposes. The panel was also used in fluoroscopic mode, acquisition rate of 3.5 frames/second, during treatment delivery. Movies of treatment delivery, 10-70 frames/movie, were acquired. Intra-fractional and inter-/intra-field (between treatment delivery/during treatment delivery) organ motion was evaluated. **Results:** To date 83 of 125 days of treatment data have been processed. Initial results indicate that intra-fractional/intra-field organ motion is rare, only 4% of days exhibit marker center-of-mass moves greater than 2 mm. Intra-fractional/inter-field motion greater than 2 mm does however occur for a significant portion of treatment days, 31% of the processed population, appearing to occur during 45-90 second intervals. Qualitative analysis indicates that a large portion of prostate shifts occur due to gas in the colon and/or rectum. Respiration does not seem to be a significant cause of prostate motion. Voluntary global patient motion appears to contribute slightly to organ motion. **Conclusion:** The prostate is fairly stable for time periods comparable to treatment delivery times, yet is less stable for longer times. A new setup protocol is proposed utilizing a step-and-shoot method of treatment. The method of patient positioning would acquire a portal image, adjust the patient based on the image and then treat that single field. This process would be repeated for each gantry angle until treatment is completely delivered, thus reducing the time between portal image acquisition and treatment delivery for a particular gantry angle.

TH-C-J-6B-08

A New Cone-Beam CT Repositioning Technique Through Deformable Registration

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Purpose: To develop a novel technique to fully utilize the 3D anatomic information provided by cone-beam CT (CBCT) on-board imager for automated patient repositioning and quantitatively evaluate its performance by comparing with the existing CBCT-guided positioning techniques. **Method and Materials:** A pelvis phantom consisting of bladder, prostate, rectum, and bony structures, was constructed and scanned using a GE Discovery-ST CT for treatment planning. After applying a deformation, it was scanned again with both Varian Trilogy on-board CBCT and the regular GE CT. The internal movement of the prostate was studied by using a BSpline deformable model. With the deformable registration, the displacement of each point in the prostate-target was obtained, and the repositioning parameters were subsequently calculated by minimizing the least-square distance of all the target points between the two setups. The method was compared with the currently used positioning methods including bony anatomy alignment and minimizing CT-number difference (MCD) via rigid transformation. **Results:** Both the proposed and the MCD method showed differences from bony anatomy alignment, reflecting the fact of independent internal organ motion. Discrepancy between the proposed and the MCD method was also observed: 12mm in x-, 9mm in y-, and 5mm in z-axis, respectively. The proposed method presented a better overall accuracy for the target localization as judged by the least-square distance. When regular CT was used instead of CBCT for positioning, consistent result was obtained by the proposed method, while the MCD method generated different positioning parameters. **Conclusion:** With the proposed CBCT-guided repositioning technique, the uncertainty of soft-tissue target localization could be greatly reduced, ensuring conformal dose distribution to be precisely delivered as planned. This also allows implementation of conformal radiotherapy with smaller margins than currently applied, leading to less complications and improved outcome of the treatment.

TH-C-J-6B-09

Image-Guided Respiration-Gated Treatment

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Purpose: Respiratory gating based on external surrogates may have large uncertainty due to the unstable correlation between external and internal signals. The purpose of this work is to use the image guidance techniques to improve the precision of external gating. **Method and Materials:** The image-guided gating procedure developed in this work including the following key components: 1) Varian RPM system for monitoring patient's respiration, 2) breath coaching technique to produce a reproducible breathing pattern intra- and inter-fractionally, 3) 4D CT simulation to acquire the accurate tumor geometric information in the gating window, 4) gated on-board kV x-ray imaging to align the target position in the gating window, 5) gated treatment delivery, and 6) kV or EPID fluoros for treatment verification. **Results:** This procedure has been applied to liver and lung patients. Here we use a liver patient with implanted fiducial seeds as an example. The patient had a peak-to-peak motion of 2 cm under free breathing, which was reduced to less than 5 mm when gated at 30% duty cycle. The patient's breathing pattern was greatly improved with the coaching technique. The fiducial seeds detected in the gated on-board x-ray images were used for patient alignment, which indicated a 5 mm systematical error and ± 5 mm random error in all three directions. The treatment was verified using the EPID in cine mode and it was found that the intra-fraction residual seed motion was about 5 mm and the inter-fraction seed motion was within +8.3/-4.5 mm in the SI direction. **Conclusion:** The utilization of image guidance techniques in simulation, patient setup, and treatment verification, along with breath coaching technique, can greatly increase the precision of the gating treatment based

on external surrogates. **Conflict of Interest:** This work was partially supported by a research grant from Varian Medical Systems, Inc..

TH-C-J-6B-10

4D Cone Beam Digital Tomosynthesis (CBDT) and Digitally Reconstructed Tomograms (DRTs) for Improved Image Guidance of Lung Radiotherapy

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Purpose: The purpose of this work is to devise an efficient, effective and routine imaging modality to guide lung radiotherapy. Current methods involve acquiring a 4D-CBCT and comparing the digitally reconstructed radiographs (DRRs) for multiple breathing phases with online fluoroscopic images. A major shortcoming of DRRs and fluoroscopy is that unwanted structures such as bones occlude the target. Furthermore 4D-CBCT requires long acquisition times and large patient dose, making it impractical for routine use. **Method and Materials:** We propose a partial arc cone beam acquisition, which we call "cone beam digital tomosynthesis" (CBDT), to obtain cross-sectional images of a slab just thick enough to enclose the soft tissue target. Projections through this slab make "digitally reconstructed tomograms" (DRTs). Similar to DRRs, DRTs correct for beam divergence. However, different from DRRs, DRTs do not contain irrelevant structures outside the slab, making the target far more conspicuous. By gating this acquisition, dynamic cross sections and DRTs are obtained at multiple respiratory phases. These dynamic images are registered with those obtained from the planning 4D-CT dataset to guide treatment. **Results:** The DRRs constructed from multiple phases of a 4D-CT emphasize bony anatomy and other irrelevant structures overlaying the target, making the edges of the target difficult to find. We have demonstrated that this difficulty is overcome by the use of cross-sectional images from CBDT and DRTs, which are obtained with an image acquisition time that is significantly shorter than full-volume 4D-CBCT. Matching DRTs were obtained from the planning 4D-CT for each phase. 2D-2D registrations were performed to obtain the phase-varying offset. **Conclusion:** A new imaging technique has been introduced for image-guided lung treatment. With this approach, images are acquired faster and the appearance of the tumor is significantly enhanced by eliminating many extraneous structures. **Conflict of Interest:** This work is supported by Siemens.

Professional Symposium — Room 618

CRCPD and Medical Physics

TH-C-P-618-01

CRCPD: Partnering With the AAPM To Assure Resolution to Radiation Protection Issues

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For the past ten years the Conference of Radiation Control Program Directors (CRCPD) and the American Association of Physicists in Medicine (AAPM) have had the pleasure of combining technical expertise from their respective fields to develop comprehensive policies, procedures, and regulations. By expanding high quality educational opportunities for CRCPD through AAPM outreach at the national and local levels, this collaborative partnership has been further strengthened.
Regulations are laborious to develop and implement through the bureaucratic maze; it is with the help of our partners that we can—through education, communication, and a cooperative spirit—prepare policies, procedures, and regulations that encourage and maintain high standards in radiation protection.
Challenges from the past and expectations of the future will be discussed from three perspectives: the national CRCPD vision (an overview from the Executive Director); a discussion of radiological terrorism and how medical physicists can play a role; and the need to proactively prepare for regulatory change in response to fast-paced technological innovation.

TH-C-P-618-02

Improved Radiation Protection in Medicine: Let's Build a Stronger Bridge and "Get Over It"

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State and Federal budgets are severely under funded. Health Maintenance Organizations and other managed care groups along with the public are demanding more of the medical industry, yet are not willing to pay more for these services. The expectation of achieving more with fewer resources at some point threatens the quality of health care, patient safety, and radiation protection of the general public.
Difficult times require difficult choices. Human and monetary resources are dwindling. Should some radiation protection efforts be curtailed or eliminated to allow the most effective programs to expand? Should the basic fundamentals behind our regulatory processes be risk-informed and performance based? Should future federal enabling legislation be refocused on programs that warrant higher attention due to increased risk? Should legislators pass on some of the costs to users? Can ambitious federal/state regulatory radiation protection programs endanger the implementation of new, more effective health care techniques? Has the time come to begin the regulation of image quality in health care? How can the unique viewpoints and goals of the regulatory and medical communities be converted to common goals through the sharing of knowledge to further ensure understanding and trust? How can members of the American Association of Physicists in Medicine (AAPM) and the American College of Radiology (ACR) work more effectively with members of the Conference of Radiation Control Program Directors (CRCPD) to answer these questions?
Past successes and present challenges before the CRCPD, AAPM, and ACR as well as answers to these questions are discussed. Some of the subtleties of image quality will be demonstrated throughout the presentation to illustrate elements of a more effective partnership in the future between the regulatory community and the medical industry. This relationship that includes regulations that support science and future clinical health care is necessary to insure safe health care at the high quality expected by the American general public—a cooperation John Villforth would applaud.

Scientific Session — Room 6C

Therapy General

TH-C-T-6C-01

A Collapsed-Cone Convolution/superposition Dose Computation Algorithm for Sliding Window Beams

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Purpose: An algorithm was developed to compute the incident energy fluence array used when computing dose for a Sliding Window beam using the collapsed-cone convolution/superposition (CCCS) dose computation algorithm. **Method and Materials:** The first step of a CCCS dose computation is the computation of the energy fluence array incident on the patient. The incident energy fluence array computation for a Sliding Window beam is the product of an opening density array (an integration over space-time of the multi-leaf collimator (MLC) leaf trajectories) and an open-field energy fluence array. An opening density represents the fraction of the time a pixel is exposed during treatment (i.e. not covered by the MLC leaves). Models of the MLC leaf end shape, tongue-and-groove and interleaf leakage effects are used by the algorithm. For an MLC with rounded leaf ends, partial transmission based on the leaf end profile model is applied to the areas that are covered by the rounded tip of an MLC leaf. Transmission corresponding to half of the leaf thickness is applied to the areas that are covered by only the tongue or the groove of a leaf. Interleaf leakage is applied to the areas that are covered by the tongue of a leaf and the groove of an adjacent (or opposing adjacent) leaf. Linear accelerator head scatter effects are also taken into account by convolving the head scatter array by the total transmission array (opening density array + leaf transmission array). **Results:** The algorithm to compute dose for a Sliding Window was implemented and released in a commercial treatment planning system. Validation results showed point dose measurement accuracy of 4 % or better in the high dose areas. **Conclusion:** The Sliding Window CCCS dose computation algorithm meets the AAPM TG 53 dose accuracy criteria (Med Phys, **25**, 1773-1829).

TH-C-T-6C-02

A Kernel-Based Model for Light Fluence Rate Calculation in Prostate Photodynamic Therapy

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Purpose: To develop a model to accurately calculate light fluence rates in prostate photodynamic therapy (PDT).
Method and Materials: A kernel-based model was developed to calculate light fluence rates in prostate PDT. A kernel was generated for each light source, which was based on the solution of the diffusion equation describing light transport in scattering media and was developed for the linear light sources used in the PDT. Light fluence rates in the prostate were obtained by summing the contributions from each light source. Optical homogeneity was assumed for each kernel. The model was applied in PDT treatment planning to predict light fluence distribution within a whole prostate in three dimensions. Light fluence rates were calculated in patients who had undergone PDT treatment and were compared with the in-vivo measurements. Calculations under different conditions, e.g., using estimated parameters or measured parameters, were compared.
Results: In the treatment planning, isodose lines were predicted and were superimposed on the ultrasound images of the patient's prostate, and the light fluence rates at the detector positions as well as in the urethra were predicted. Comparisons were made between the calculations and measurements among 12 patients with: (1) measured or estimated mean optical property (uniform source strength, 150 mW/cm), and (2) measured or estimated mean optical property (actual source strengths). The errors of the calculations using actual source strengths were smaller than those using the uniform source strengths, which had maximums of 500% and 400%, respectively, among the 12 patients. Using actual source strengths, the average errors of the calculations over 12 patients, were ~89% and ~104% using measured and the mean optical property, respectively.
Conclusion: The study indicates that accurate source strengths are important in the calculations and accurate optical properties are necessary for accurate calculations of light fluence rate distribution.

TH-C-T-6C-03

A Method for Computing Energy Spectra for Multiple Orders of Compton-Scattered Photons

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Purpose: To compute the energy spectra for the first several orders of scatter for Compton-collided photons and to discuss the results with respect to radiation transport and radiation protection considerations. **Method and Materials:** We assume that a population of monoenergetic, isotropically-emitting point sources is uniformly distributed throughout an infinite, homogenous medium, which is characterized by isotropic scattering and no absorption. With these assumptions, the Boltzmann transport equation is written as a function of energy only, and is numerically solved by the Neumann Series method, which treats the transport problem as a coupled set of integral equations – one for each order of collision. **Results:** The differential energy spectra (photons / cm2-sec-MeV versus energy) for the first five orders of scatter are shown for a variety of initial photon energies in water, and in lead. These plots share several similar characteristics. First, the collision spectra become increasingly Gaussian-shaped with each increase in order of scatter. Second, the peak for each spectrum shifts to lower energies with each scatter. However, the magnitude of this energy shift decreases with each progressive increase in order of scatter. Finally, the shapes of the collision spectra do not depend on the scattering medium; only their scale changes according to a ratio of electron densities.

Conclusion: A tool has been developed to compute the energy spectra for the first five orders of Compton-collided photons that result after scattering from an arbitrary initial energy in a homogeneous medium of arbitrary material. These spectra illuminate properties of the Klein-Nishina formula for Compton collisions and are useful for radiation transport problems where one needs an estimate of the expected population of scattered photons in the Compton energy regime. Future work will build photoelectric absorption into the model.

TH-C-T-6C-04

Estimation of Tumor Dose Enhancement Due to Gold Nanoparticles During Typical Radiation Treatments: A Preliminary Monte Carlo Study

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Purpose: To computationally demonstrate possible tumor dose enhancement due to the use of gold nanoparticles and to provide quantitative estimates of this tumor dose enhancement during typical radiation treatments. **Method and Materials:** This investigation was conducted with several phantom test cases that simulated typical radiation treatments using orthovoltage x-rays, high energy photon beams from linear accelerators, and gamma rays from a brachytherapy source. Specifically, possible dose enhancement within a tumor loaded with gold nanoparticles was calculated by Monte Carlo calculations when the phantoms were irradiated by 140 kVp x-rays, 4 and 6 MV photon beams, and ^{192}Ir gamma rays. Based on published mice studies, the current study considered three levels of gold concentration within the tumor: 7, 18, and 30 mg Au / g tumor. The Monte Carlo calculations were performed with the BEAMnrc/DOSXYZnrc code system for the external beam cases and with the MCNP5 code for the ^{192}Ir cases, respectively. **Results:** The dose enhancement over the entire tumor volume considered for the 140 kVp x-ray case can be at least a factor of 2 at an achievable gold concentration of 7 mg Au /g tumor. The tumor dose enhancement for the cases involving the 4 and 6 MV photon beams ranged from about 18% to 60%, depending on the amount of gold within the tumor and photon beam qualities. For the ^{192}Ir cases, the dose enhancement within the tumor region ranged from 5% to 31%, depending on radial distance and gold concentration level. **Conclusion:** The tumor dose can be enhanced significantly by using gold nanoparticles during typical radiation treatments, assuming that the findings from previous mice studies would be applicable in humans. **Conflict of Interest:** This investigation was supported in part by PHS Grant No. CA 10953 awarded by the National Cancer Institute, Department of Health and Human Services.

TH-C-T-6C-05

Evaluation of TomoTherapy's MVCT Number Integrity

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Purpose: Megavoltage CT (MVCT) images of patients are acquired daily on a helical tomotherapy unit (TomoTherapy, Inc., Madison, WI). While these images are primarily used for patient alignment, they can also be used to recalculate the treatment plans in the daily anatomy. This, however, requires a reliable CT number to electron density calibration curve. We tested the integrity of the MVCT numbers by determining the variation of this calibration with time, spatial arrangement of the calibration phantom, and MVCT acquisition parameters. **Method and Materials:** To evaluate the stability of the calibration with time a CT to electron density phantom was scanned repeatedly over time intervals up to 9 months. To test the sensitivity to the spatial phantom arrangement the outer and inner ring test plugs were exchanged. The phantom was scanned with different pitch ratios to test for any sensitivity to this parameter. MVCT scans encompassed the length of the phantom plus a region where the test plugs are extended into air. These in-air slices were compared with the in-phantom slices. The two calibration curves that enveloped all observed variations were applied to six clinical MVCT images for recalculations to test for dosimetric uncertainties. **Results:** The largest variation of the calibration curve was observed between in-air and in-phantom scans. For the two extreme test plugs the scans the MVCT numbers differed by up to 82 MVCT numbers. Using these two calibration curves, the largest difference in any of the dosimetric endpoints among the clinical images was 3.1 % . More typically the dosimetric endpoints varied by less than 2 %. **Conclusion:** The stability of the electron density calibration curve is comparable to that of kVCT scanners and allows the establishment of a reliable MVCT to electron density calibration. **Conflict of Interest:** Three of the co-authors are employees of TomoTherapy, Inc.

TH-C-T-6C-06

Feasibility of Dynamic Feathering for Field Junctions

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Purpose: Patients are not perfectly immobilized and there is always some movement during treatments. Field junctions are typically shifted several times during the course of treatment to ensure that the effects of imperfect junctions and patient motion are minimized. We have evaluated a dynamic feathering scheme that reduces daily hot and cold spots at field junctions, and may eliminate the need for junction shifting in the future. **Method and Materials:** Five craniospinal patients were planned using both conventional and dynamic feathering techniques. Using conventional feathering, the inferior border of the cranial fields were moved after each set of 5 fractions by increasing the inferior borders by 1 cm and closing the spine field by 1 cm. In the second plan we simulated an automated feathering technique in which the cranial fields opened dynamically and the spine field closed at the same rate, thus using one set of beams for the entire treatment. Patient motion of up to 5 mm was simulated and the dose distributions were analyzed. Film verification was performed to verify dose distributions. **Results:** Comparison between the conventional and dynamic feathering plans show a slight advantage to automatic feathering. However, in conventional cases where 5 mm overlap is simulated, hotspots of 51%-63% were observed, but these were reduced to 33% using dynamic plans. Besides, only 44% of the prescribed dose covered the spinal cord at the junction for the conventional plan while 89% for the dynamic plan if 5 mm of gap was simulated. **Conclusion:** Dynamic feathering yields better dose homogeneity and reduces the effects of overlapping or over-gapping field matches on a daily basis. This technique requires only a single plan, which reduces the workload on the physicists, dosimetrists, and therapists. In our continuation of this work we are investigating automated dynamic feathering on our linac.

TH-C-T-6C-07

Is Cone Beam CT Suitable for Dose Verification?

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Purpose: To evaluate the influence of cone beam CT (CBCT) on dose calculation accuracy and check if CBCT is suitable for the daily dose verification of patient treatment. **Method and Materials:** A CT-calibration phantom was first used to calibrate both conventional CT (GE Discovery-ST) and CBCT (Varian Trilogy OBI system). CT and CBCT images of the calibration phantom, an anthropomorphic phantom and a lung patient were then acquired for this study. The HU profiles along two orthogonal lines were acquired and compared for both CT and CBCT. CT and CBCT images were then imported to a treatment planning system (Varian Eclipse). Treatment plans were generated based on both CT and CBCT and the resultant dose distributions were compared based on isodose curves, dose profiles and DVHs. The various factors causing the dosimetric inaccuracy in CBCT-based planning were analyzed. **Results:** Even though the same calibration was used for both CT and CBCT-based planning, the difference in the HUs between the CT and CBCT was found to be clinically significant. The discrepancy was most pronounced in the regions close to the phantom surface, with the maximum difference reaching 400 HUs. For the same planning condition (geometric setups, energy, MU, and dose calculation algorithm), ~3% dose difference was found in the two planning schemes for the phantom. For the lung case, the maximum dose discrepancy was found to be ~7% due to the motion artifacts in CBCT. **Conclusion:** Although CBCT provides useful volumetric anatomy information for patient positioning verification, when used for dose calculation, it could introduce clinically unacceptable dosimetric errors. The quality of current CBCT should be improved in order for it to be used routinely for dosimetric verification calculation.

TH-C-T-6C-08

Initial Experiences with a Dynamic Treatment Simulation System

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Purpose: To present our initial experience with an in-house developed dynamic treatment simulation platform, PortSim, and evaluate its performance characteristics in the context of conventional and IMRT simulation. **Method and Materials:** PortSim is a software package that interfaces with a conventional simulator that operates in fluoroscopic mode. A frame grabber is used to obtain live images from the image intensifier (II). The patient's treatment plan, including DRRs, beams, contours and MLCs can be imported into the PortSim environment. The distortion corrected fluoroscopic images can be compared against the DDRs and verify beam and isocenter placement. Both static and dynamic MLCs can be superimposed on the fluoroscopic images to verify beam aperture prior to treatment. Volume contours can also be projected to verify target position and coverage. Patient setup and targeting uncertainty can be quantified at the time of the simulation. The complete simulation process can be recorded for later review and analysis. **Results:** The PortSim system enabled us to increase our simulation throughput by 30%. It provided a film-less environment for patient simulation and verification. The maximum image distortion correction error is less than 2 mm, making the digital images readily usable for review and planning purposes. Physician subjective error in reviewing films was significantly reduced due to the improved image quality, direct overlay of DRR and contours. The software allows for DICOM import and export to other devices, including printers. **Conclusion:** We have developed a comprehensive software package that allows us to improve significantly our film review during the patient's treatment simulation. With features such as direct overlay, side-by-side display on the same screen and improved image quality we can perform simulations more efficiently and more accurately. The simulation process can be recorded and provide valuable information for improving field design and patient immobilization techniques.

TH-C-T-6C-09

Measurement of Shielding Requirements for Helical Tomotherapy

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Purpose: Helical tomotherapy is a CT-based rotational delivery technique that uses intensity-modulated fan beams to deliver highly conformal intensity modulated radiation therapy (IMRT). The purpose of this work is to directly measure and map the radiation environment around a clinical TomoTherapy HI-ART system during patient treatments to determine the rate of in-room exposure. **Method and Materials:** Radiation exposure was measured at various positions surrounding a helical tomotherapy treatment system using a calibrated InoVision Model 451P ionization chamber. The 451P has a 300 cubic centimeter collecting volume air ionization chamber that is pressurized to 8 atmospheres (862 kPa). Prior to use in this study, the chamber was calibrated by an Accredited Dosimetry Calibration Laboratory (ADCL) and is directly traceable to the National Institute of Standards and Technology (NIST) standard. **Results:** A total of 225 measurements were taken during helical treatment delivery for 25 patients at various positions around the HI-ART gantry. The largest measured exposure rate is 1 mR/sec in the plane of gantry rotation from head leakage and primary beam transmission through the beam-stopper. There are 2.2 million seconds of beam-on time annually assuming an average beam-on time is 300 seconds, an average treatment slot of fifteen minutes, and patients per hour. Based on the measured scatter and leakage values, a total of 3 to 5 TVLs of secondary beam shielding is required, depending on the room geometry, patient load, occupancy factors, and dose limits. **Conclusion:** Based on the primary, leakage, and scatter exposures measured around the HI-ART it is possible to replace a conventional linear accelerator with a helical tomotherapy system without requiring additional primary or secondary shielding.

TH-C-T-6C-10

Simulation of Dosimetric Properties of Very-High Energy Laser-Accelerated Electron Beams

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Purpose: The dosimetric properties of "quasi-monoenergetic" very-high energy (170MeV+-20MeV) laser-accelerated electrons are studied to

evaluate the adequacy for radiotherapy. **Method and Materials**: The experimental properties of a laser-accelerated electron beam are used. The Gaussian shaped high-energy part of the spectrum and the divergence of 10 mrad at FWHM are used as the initial phase space for Monte Carlo simulations. The dose distribution in a water phantom of an electron beam produced by one single laser shot is computed. The simulations are performed with Geant4 and include electro-magnetic interactions and electron-/photon-nuclear processes. The depth dose curve and the lateral profiles are determined. Furthermore penumbras of a 6x6 cm² treatment field and absolute dose values are given. In addition the dose deposition by electron- and photon-nuclear processes is quantified. **Results:** The depth dose curve shows a maximum at a depth of 19.2 cm. The lateral fluence profiles can be characterized by a sum of a Gaussian distribtution, which results from multiple Coulomb scattering, and a Lorentzian distribution. The widths of the distributions increases from 3.0 mm at the beginning of the phantom to approximately 10.0 mm at a depth of 15.0 cm. The penumbra defined as the distance between 80% and 20% dose for depths of 10 cm, 20 cm and 30 cm are 9.0 mm, 18.0 mm and 28.0 mm respectively. The dose on the central axis for the treatment field, measured at the maximum of the depth dose curve, is 18 Gy. One way to reduce this dose is to vary the electron gas density. The reduction by a factor of 10 has been seen experimentally while a further reduction has to be investigated. **Conclusions:** In order to investigate the clinical potential of very-high energy laser-accelerated electron beams the dosimetric characteristics will be implemented in a treatment planning system.

Therapy Scientific Session — Room 617
Monte Carlo Methods 2

TH-C-T-617-01
A Proposed Alternative to Phase-Space Recycling Using Adaptive Kernel Density Estimator

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Purpose: To investigate the adaptive kernel density estimation (AKDE) method as an alternative to recycling phase-space (PS) files or histogram binning during MC accelerator simulation. The AKDE approach has the potential to mitigate statistical "noise" issues (due to latent variance) in the PS data, without the need for an overwhelmingly large number of particles. **Method and Materials:** We have implemented a nonparametric density estimation technique, the AKDE method, to generate additional PS variables in the vicinity of simulated PS points in MC accelerator simulation. The method involves the placement of kernels at simulated PS points, and the window-width is allowed to vary based on the density of the PS points. After successfully testing the method for sampling 1-D and 2-D exponentials we sampled PS files generated from accelerator simulations. The original PS (x, y, u, v, E) was reduced to a rotationally invariant PS (r, θ, α, E) assuming azimuthal symmetry above the collimating jaws. The new PS point $(r', \theta', \alpha', E')$ is generated by sampling in the vicinity of (r, θ, α, E). To test the method we simulated dose profiles for a 10x10cm^2 field using 1x10^6 particles in the PS file as input. **Results:** Results indicate that a minimum number of PS points are needed to allow accurate density estimation. Preliminary calculations using a global window-width for each PS variable produce relatively smooth profiles even with as little as 10 million particles in the PS file. However, profiles with the Epanechnikov kernel appear to be smoother and in better agreement with the original PS versus either Gaussian or uniform kernels. **Conclusion:** By generating unbiased PS samples "on-the-fly" in the neighborhood of simulated PS points AKDE has been shown to be a promising alternative to PS recycling or histogram-binning (source modeling), where binning effects and propagation of systematic latent uncertainties may pose potential problems.

TH-C-T-617-02
Effect of Range Modulation On Neutron Dose Equivalent Exposures Around a Passive Scattering Proton Therapy Treatment Nozzle

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Purpose: The purpose of our study was to examine the influence of range modulation on the neutron dose equivalent exposures outside the treatment volume around a large-field passively scattered proton therapy treatment nozzle. **Method and Materials:** In this study, the neutron dose equivalent spectra per proton ($H(E/p)$) and total neutron dose equivalent per therapeutic absorbed dose (H/D) were calculated using Monte Carlo simulations of the neutron fluence and the energy dependent neutron fluence-to-dose equivalent conversion factor for NCRP 38. ($H(E)/p$) and H/D were calculated at 54 locations around a passively scattered proton therapy treatment nozzle for varying amounts of range modulation. **Results:** As the step thickness of the range modulator wheel increased from 1.0 to 12.0 cm, the peak values of $H(E)/p$ increased from $1 \cdot 10^{-17}$ to $2 \cdot 10^{-17}$ mSv/Gy at 50 cm from isocenter along the beam's central axis. In general, H/D increased with increasing range modulation at all locations studied, and the maximum H/D exposures shifted upstream of isocenter and away from the end of the nozzle. **Conclusion:** Several important findings can be summarized from the presented work. First, with increasing thickness of the RMW step, the high-energy peak in the $H(E)/p$ spectra shifted to higher energies. Second, at 90° with respect to the proton beam axis, the high-energy peak occurs at substantially lower neutron energies. Also, the H/D values around the treatment nozzle increased as the modulation of the beam increased. Finally, the H/D values change significantly with distance from isocenter and angle with respect to the incident beam axis, due in part to the effects of the nozzle components on the neutron fluence downstream of the end of the nozzle.

TH-C-T-617-03
Implementation of Monte Carlo Dose Verification for Proton Therapy QA

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Purpose: The use of proton beams provides the possibility of superior dose conformity to the treatment target as well better normal tissue sparing as a result of the Bragg peak effect. Recently, more effort has been dedicated to the investigation of practical solutions to compact, flexible and cost-effective proton therapy systems. The purpose of this work is to develop a Monte Carlo based dose verification tool for proton therapy treatment planning and beam delivery. **Method and Materials:** As a part of this project, a Monte Carlo dose verification tool is developed based on the FLUKA Monte Carlo code and the MCSHOW graphic user interface. Direct Monte Carlo simulations included detailed physics of hadron, neutron, electron and photon interaction and transport. Magnetic field and beam modifiers are implemented to change the beam direction and shape. Phase space files and intensity maps are used to reconstruct the proton intensity distribution for each treatment field. The FLUKA voxel geometry is extended to read DICOM image files from CT and MR scans to reconstruct patient geometry for accurate dose calculation. Dose results will be displayed using MCSHOW on top of patient anatomy and analyzed to output DVH information. **Results:** We have commissioned the FLUKA code system for radiotherapy dose calculation by comparison with other Monte Carlo systems including GEANT3/4 and the latest version of MCNPX. Consistent (within 2%) results were obtained among these codes and previously published measurement data. We also validated our implementation for various energy combinations and intensity modulation/weight adjustment for intensity-modulated proton therapy. **Conclusion:** A useful Monte Carlo based dose verification toolkit has been developed for proton therapy research and clinical dose calculation. It will play an important role in the quality assurance for proton therapy treatment planning and dosimetry verification.

TH-C-T-617-04
Measurements and Monte Carlo Simulations of Dose Perturbations Due to Metallic Implants in Proton Radiotherapy

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Purpose: To quantify the dose perturbation behind implanted metallic appliances and fiducials in proton radiotherapy. **Method and Materials:** Dose perturbations from stainless steel spheres of 6.4-15.9 mm diameter were investigated in proton therapy beams. Passive lateral spreading was combined with collimation to produce 17.8-cm diameter fields. Penetration ranges were varied between 40 and 160 mm. Dose profiles were measured

in planes perpendicular to the proton beam axis, at distances of 0-150 mm behind the implants, using radiographic film exposed to 0.4-0.5 mGy. The experiments were modeled in detail with Monte Carlo simulations that included hadron and electron transport physics. $120x10^6$ proton histories were simulated, corresponding to 8% or less statistical uncertainty. **Results:** Edge effects are most prominent at the highest proton beam energies and produce concentric perturbations of +/-10-40% for the implants considered here. Thick implants (w.r.t. the beam range) may stop the protons, leaving a zero dose shadow behind it. For thin and intermediate implants, the range loss in the implant produces a cone of dose enhancement of up to 20% directly behind the implant due to in increase in the stopping power values. In an air cavity, shadows reduce the dose by up to 60% at 15 cm distance downstream from the implant. The Monte Carlo simulations agree with the measurements to better than 8% in all cases and typically to within 4%. Additional simulations will be presented for implants of gold and tantalum, ranging in size from 0.8 to 3 mm. **Conclusion:** We have identified several representative cases in which implants produce significant dose perturbations. In such cases, a treatment plan should include suitable simulations or measurements to ensure that the implants do not result in cold spots in the tumor or hot spots in normal tissue.

TH-C-T-617-05

Monte Carlo Simulations of a Nozzle for the Treatment of Ocular Tumors with High-Energy Proton Beams

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Purpose: To develop a Monte Carlo simulation model for ocular proton beam therapy, validate its predictions with measurements, and commission an ocular treatment planning system using simulated proton beam data. **Method and Materials:** We commissioned the EYEPLAN ocular treatment planning system for proton radiotherapy using only dosimetric data from Monte Carlo simulations. The commissioning comprised two main tasks: generating nozzle-specific parameters and dose profiles and entering them into the treatment planning system, and testing the accuracy of the planning system's dose predictions under various beam conditions that are representative of ocular melanoma treatments. The MCNPX Monte Carlo simulation code was used with a detailed, 3-dimensional model of an ocular beamline. Simulations were carried out to generate both input dose distributions for the treatment planning system as well as validation data to test the accuracy of the TPS predictions. The simulation model was benchmarked against measured dose distribution from Harvard Cyclotron Laboratory (Cambridge) and the Northeast Proton Therapy Center (Boston). Measurements were made with ionization chambers, diodes, and radiographic film. **Results:** Benchmark comparisons revealed maximum differences between absorbed dose profiles from simulations and measurements of 6% and 0.6 mm, while typical differences were less than 2% and 0.2 mm. The computation time for the entire virtual commissioning process is less than one day. **Conclusion:** The study revealed that, after a significant development effort, a Monte Carlo model of a proton therapy apparatus is sufficiently accurate and fast for commissioning a treatment planning system. With relatively little additional effort, additional capability can be added to the model, such as the prediction of output factors.

TH-C-T-617-06

Error Analysis in Monte Carlo Simulation of Low Energy Brachytherapy Sources

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Purpose: The AAPM recommends two independent investigators to determine the dosimetric characteristics of any new brachytherapy sources before their clinical applications. In this recommendation, it is suggested that one of the two investigators must include Monte Carlo simulation technique. The accuracy of Monte Carlo simulation technique is highly dependent on accuracy of the source geometry and material information that is provided by the manufacturers, and the approximations taken during the simulations. In the present work, the effects of various parameters like configuration of active pellets, outer wall thickness and end cap thickness on the accuracy of the dosimetric characteristics of the brachytherapy sources have been investigated. Also, studies were performed to determine the effect of embedded radioactive elements within the source, and effect of number of histories used for calculating the dosimetric parameters. **Method and Materials:** Monte Carlo simulation code PTRAN version 7.43 was used to simulate the source designs in water medium. The photon cross section used for these simulations was DLC-146, distributed by the Radiation Sciences Information Computing Center at Oak Ridge National Laboratory. The variations of dosimetric characteristics of different brachytherapy source design with a fixed radionuclide were obtained following the AAPM TG-43U1 recommendations. **Results:** The results of these investigations showed that the anisotropy function and anisotropy factors of the source were considerably affected by the thickness of the outer wall and end caps. Whereas, the radial dose function and the dose rate constant were not significantly affected by these parameters. Moreover larger histories are required to obtain dosimetric characteristics at larger distances with acceptable (< ± 2%) statistical uncertainty range. **Conclusion:** This study suggests that the Monte Carlo simulated 2D anisotropy functions for low energy brachytherapy sources are very sensitive to the geometric parameters of the source and number of histories used in simulation.

TH-C-T-617-07

MCPI, An Accelerated Monte Carlo Dose-Calculation Engine for Real-Time Prostate Implant Dosimetry

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Purpose: To present a new accelerated Monte Carlo code (MCPI: Monte Carlo for Prostate Implant) intended for use as a dose calculation engine for planning clinical prostate implants. MCPI simulates physically a set of radioactive seeds with arbitrary positions and orientations, merged in a 3D CT-based heterogeneous phantom representing the prostate and surrounding tissue. **Method and Materials:** MCPI uses a phase space data source-model to account for seed self-absorption and seed anisotropy. A "hybrid geometry" model (full 3D seed geometry merged in a 3D mesh of voxels) is developed for rigorous treatment of the interseed attenuation effect. MCPI is based upon the GEPTS general-purpose Monte Carlo code. Compton scattering, coherent scattering, and photoelectric effect (with emission of fluorescence X-rays) are modeled in detail, using the XCOM/EPDL97/NIST95 cross-section data. MCPI is benchmarked against the MCNP5 code for the case of an idealized prostate implant, consisting of 83 ^{103}Pd (or ^{125}I) seeds. **Results:** MCNP5 and MCPI are in excellent agreement. The average difference between the dose distributions from the two codes is less than 0.5% for both seed models. For a $2\times2\times2$-mm^3 voxel mesh, MCPI calculates the ^{103}Pd and ^{125}I prostate dose distributions with 2% average statistical uncertainty in 2.1 to 2.2 minutes using a single Pentium 4 PC. More than 3 hours calculation time is required for MCNP5 to achieve the same statistical precision. MCPI is about 90 and 700 times faster than MCNP5 for 2 and 1-mm^3 voxels, respectively. **Conclusion:** The use of multiprocessor parallel calculation can further increase the speed of MCPI and makes sub-minute dose calculations for prostate implant planning a reality.

TH-C-T-617-08

Monte Carlo Modelling of the Response of NRC's 90Sr/90Y Primary Beta Standard

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Purpose: To benchmark an EGSnrc Monte Carlo calculated response against the high quality measured response of an extrapolation chamber used as NRC's primary standard of absorbed dose to tissue in a ^{90}Sr/^{90}Y beta field. **Method and Materials:** The BEAMnrc code was used to model the NRC's beta source and indigenously developed extrapolation chamber. The calculated response was compared to the measured response in 3 different series of measurements. An overall scale factor was determined by a global fit. It was used to scale the calculated values to the measured values and was compared to the known activity of the source. A single measurement configuration (30 cm distance, 0.2015 cm chamber depth) was common to all 3 sets of experimental data. **Results:** The scale factor led to an estimated source activity of 1.237±0.08% GBq which is consistent with the nominal value of 1.2±0.1 GBq. As the source-detector distance was varied from 11 cm to 60 cm, values of calculated and measured

responses agreed within 0.37% for a variation in response by a factor of 29. As chamber depth was varied from 0.05 cm to 0.25 cm the values agreed within 0.4%. As Mylar thicknesses up to 11 mg/cm^2 were added to the face of the chamber, the values agreed within 0.2%, and agreed within 1.2% up to 150 mg/cm^2. **Conclusion:** This project demonstrates EGSnrc's ability to calculate the response of extrapolation chamber with a remarkable degree of accuracy. Such high precision comparisons with experimental data are rare. This benchmarking of the Monte Carlo model will allow it to be used to calculate correction factors needed for the NRC's primary standard.

TH-C-T-617-09

Wide Energy Metallic Build-Up Caps for MOSFET Dosimeters: Monte Carlo Simulation and Experimental Study of Dose Correction Factors at Dmax

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Purpose: Current MOSFET dosimeters use large size (2cm) solid water build-up caps at high energies for patient dose measurements at Dmax, less practical for routine use. Dense metallic materials have been studied to reduce the amount of build-up needed to achieve electronic equilibrium at Dmax, and extend the MOSFET clinical use. **Method and Materials:** The caps studied were hemispherical, with a groove to secure the MOSFET detector. The radiation tests were performed on brass, aluminum and plastic-water equivalent caps. Monte Carlo simulations of depth dose curves in the central axis of the geometry were performed to evaluate the cap effect on the dose measurements. Correction factors to scale the dose value at Dmax in water were also measured for each cap at 6 and 23 MV photon beams. Linearity and angular responses were also evaluated. **Results:** At 6 MV and 10x10 cm² field (100 cm SSD), the correction factors were for aluminum (R 10 mm), brass (R 6.35 mm) and solid water (R 2 cm) caps, 0.96, 0.9 and 0.97 respectively. At 23MV and for similar caps, the correction factors were 0.97, 1.19 and 0.84 respectively. The brass cap is the only cap to achieve electronic equilibrium at both energies for the smallest size possible (6.35 mm). Its slight over response at 23MV is linked to its high atomic number. Its hemispherical shape ensures isotropic response up to 40 º, and only 3 % SD was observed for angles close to 90 º around the central axis at 6 MV. **Conclusion:** The smallest brass build-up cap is highly suitable to create a full build-up for MOSFET measurements at high energies. Correction factors can be obtained for all photon energies, making routine in-vivo dosimetry easily feasible for different beams. **Conflict of Interest:** Research supported by Thomson Nielsen Inc.

TH-C-T-617-10

Monte Carlo Investigation of Heterogeneity Effect for Head and Neck IMRT

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Purpose: The purpose of this work is to verify the accuracy of the dose distribution calculated by the CORVUS treatment planning system and to investigate the heterogeneity effect on head and neck IMRT plans using Monte Carlo simulations. **Method and Materials:** A Monte Carlo dose calculation tool, MCSIM, was used to carry out patient-specific dose calculations. Patient-specific CT data and the IMRT RTP files generated by the CORVUS treatment planning system were used for Monte Carlo dose calculations. Ten head and neck IMRT treatment plans were re-calculated and compared with the original plans. The isodose distributions and the dose-volume histograms were used for comparison. In order to investigate the heterogeneity effect for head and neck patient, IMRT plans generated by CORVUS with and without heterogeneity correction were compared with Monte Carlo dose distributions re-calculated under the same conditions. **Results:** The mean target dose and the dose at the isocenter predicted by CORVUS agreed to within ±5% of those predicted by Monte Carlo for all cases. Hot spots and cold spots were observed in the target volume due to the heterogeneity effect in some patients with beams going through bones, teeth and/or air cavities. D95 (dose received by 95% of the target volume) recalculated by the Monte Carlo method could be 8% lower than the original plan, which is outside the clinical acceptance criterion. More than 10% differences in the critical structure dose were also observed. **Conclusion:** In general, dose distributions from CORVUS with heterogeneity correction agreed to within ±5% with Monte Carlo calculations. Cold spots in the target volume due to inaccurate heterogeneity correction may compromise the local control of head and neck IMRT. The dosimetry differences in critical structures are another aspect worthy to be further investigated.

Therapy Scientific Session Room 6E

IMRT Verification and Quality Assurance 2

TH-C-T-6E-01

A Comparison of Three Ionization Chambers for IMRT Patient Specific Quality Assurance

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Purpose: To compare fifty IMRT patient specific point dose measurements between three thimble-type ionization chambers of varying volumes, and with dose calculations from a commercial treatment planning system (TPS). **Method and Materials:** Fifty patient plans were recomputed with unmodified fluence patterns on three separate CT image sets of a 30x30x17 cm^3 solid water phantom and three different ionization chambers: 0.6 cm^3 NE 2571 Farmer; 0.125 cm^3 Wellhofer IC10; and 0.015 cm^3 PTW Freiburg 31006 PinPoint. Dose volume statistics were generated by the TPS over outlined chamber volumes, as seen on the scans. The phantom and chamber were set up on the treatment couch and irradiated as would have been for one patient's fraction. IMRT measurement reproducibility, and the TPS dose calculation accuracy under reference conditions was evaluated. Chamber-type to chamber-type differences, as well as differences between measured and treatment planning dose calculations were compared. **Results:** The PinPoint chamber experienced the most inferior reproducibility (3.57%) as well the greatest discrepancy from the dose calculation of the TPS. For the same delivery, chamber-type to chamber-type response can vary by up to 8%. The average of the ratios of PinPoint-to-NE2571 and IC10-to-NE2571 measured absorbed dose to water, for 50 IMRT plans, amounts to 1.023 ± 0.005 and 1.007± 0.003, respectively. The corrected ionization measurement and TPS dose in IMRT fields were normalized to the values in reference conditions, i.e., we compared $D_{TPS}^{IMRT} / D_{TPS}^{ref}$ with M_c^{IMRT} / M_c^{ref}. The mean ratios of $(D_{TPS} / M_c)_{ref}^{IMRT}$ for the PinPoint, IC10, and NE2571 are 0.933, 0.940, and 0.948 respectively, illustrating a 6% difference in TPS predicted chamber dose and measured signal **Conclusion:** The chamber-type-to-chamber-type dose measurement variation is systematic for the dosimeters used. The application of the absorbed dose to water calibration coefficient, which was determined under reference conditions may not hold in IMRT fields, whose specific characteristics are not known.

TH-C-T-6E-02

An Independent Dose Verification Method for Dynamic Intensity Modulated Radiation Therapy

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Purpose: Dosimetry verification is particularly important especially for intensity modulated radiotherapy where the dose delivery technique is complex.. The dosimetry verification is usually conducted with measurements and independent dose calculations. However, currently available independent dose calculation methods were developed for step and shoot beam delivery method, and their uses for dynamic MLC delivery method are not clear. In this study, a dose calculation method was developed to perform independent dose verifications for dynamic MLC-based IMRT technique. **Method and Materials:** This method extracts the machine delivery parameters from the dynamic MLC(dMLC) files generated by the IMRT treatment planning system. Based on the machine delivery parameters, a monitor unit (MU) matrix, including both primary and leakage contributions, was generated. The MU matrix was used to compute the primary dose matrix and scattered dose matrix. The scattered

dose was derived based on the Modified Clarkson technique. **Results:** The doses computed using this method were compared with both measurement (14) and treatment plans (25). The doses calculated using this method, on average, agreed with the measured doses to within 1% with a standard deviation of 1.9%. The computed and planned doses agreed to within 2% with a standard deviation of 1.5%. **Conclusions:** An independent dose calculation algorithm has been developed to perform independent dose verifications for dynamic IMRT plans. The algorithm independently computed doses that were in excellent agreement with the doses from from commercial treatment planning system. This independent dose calculation method may potentially be used for routine IMRT plan verifications.

TH-C-T-6E-03

CORVUS IMRT Film DosimetryUsing Novel GafChromic EBT Film

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Purpose: To evaluate the new EBT GafChromic film for IMRT relative and absolute film dosimetry and to investigate its application for IMRT QA. **Method and Materials:** EBT GafChromic film (ISP, Wayne, NJ) was compared with EDR2 (Eastman Kodak, Rochester, NY) for IMRT treatment planning QA. The IMRT QA procedure was described previously (1). The IMRT treatment plans were generated on a Corvus (Nomos, NAS, Cranberry Township, PA) treatment planning system for a 25 cm x 25cm x 25cm phantom, using a 23MV photon beam (Siemens, Primus 23). The planning isodose distribution was compared with the measured isodose distribution in the transverse plane that included the isocenter. Film dosimetry was performed using a Vidar VXR-16 Dosimetry Pro scanner (Vidar, Herndron, VA) and RIT 113(Colorado Springs, CO) software. Contour MSKCC software was used for dose overlays. **Results:** The EBT film scanning intensity on the Vidar scanner depends on film scanning direction. The intensity difference is 13%-20% between scans of the same film rotated by 90°. For film dosimetry this requires the H&D curve films and QA films to be scanned in the same direction. The isocenter dose difference between dosimetry in each direction is up to 2%, mixing scanning directions can cause a dose difference of 30%. The difference in dose value at the isocenter between the plan and EBT film was 1.6%-5.1%. **Conclusion:** The EBT provides quantitative 2D dose measurements in high gradient rapidly changing IMRT fields and has dosimetry accuracy comparable with EDR2. The film scanning direction is critical for absolute dose evaluation. **Conflict of Interest:** The EBT film for this research was provided by ISP Corporation.

1. M Kao *et al.* Using Conventional Solid Water Phantom for IMRT Patient Treatment Quality Assurance, Med. Phys. 30, 1495 (2003) (Abstr.)

TH-C-T-6E-04

Evaluation of a New 3D Polyurethane Dosimeter for IMRT Verification

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Purpose: To demonstrate the dosimetric accuracy of PRESAGE™, a new type of three-dimensional dosimeter, when used in the Radiological Physics Center's (RPC) Head and Neck Phantom. **Method and Materials:** An IMRT treatment plan was developed for the RPC Head and Neck Phantom, which contained simulated planning target volumes and an organ at risk. A conventional dosimetry insert, containing radiochromic film and TLD, was in place while the IMRT plan was delivered. The insert was removed and replaced with a PRESAGE™ dosimeter and delivery of the IMRT plan was repeated. An additional PRESAGE™ dosimeter was irradiated to doses between 0.5 and 7.5 Gy with stereotactic beams to develop a calibration curve. The PRESAGE™ dosimeter was imaged using an OCT-OPUS™ laser CT scanner 24 hours after irradiation. Two-dimensional comparisons were performed between the treatment plan, the distribution measured with film/TLD and the distribution measured with PRESAGE™. **Results:** The PRESAGE™ dosimeter showed a monotonic and easily characterized response with dose. Optical density maps obtained following IMRT delivery were converted to dose and compared with the treatment plan and with film/TLD data. Film and PRESAGE™ data showed good agreement, and both indicated higher doses in the steep gradient region between the PTV and the organ at risk. **Conclusion:** This work demonstrated the use of PRESAGE™ as a dosimetric tool for the verification of IMRT treatments. The dosimeter provided a three-dimensional distribution that was used for comparisons with treatment plan distributions.

The investigation was supported by PHS grants CA 10953 and CA81647 awarded by the NCI, DHHS.

TH-C-T-6E-05

Evaluation of GafChromic EBT Film for IMRT QA Using Two Different Scanners

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Purpose: Absolute film dosimetry for IMRT QA using radiographic film is very time- and film-consuming because of film processing uncertainties. Radiochromic film requires only one calibration curve per energy per production lot. Applicability of new GafChromic EBT film for absolute IMRT dosimetry using two different film scanners was evaluated. **Method and Materials:** GafChromic EBT (ISP, Wayne, NJ) and Kodak EDR2 films irradiated in polystyrene phantoms on a Varian 2100C/D linear accelerator were compared using the Vidar VXR-16 DosimetryPro and Epson Expression 1680 scanners. Vidar scanning was done with RIT113 software and a yellow filter for the EBT. Epson scans were done with the scanner software in 48 bit color, followed by red channel extraction. EBT films were scanned 24 hours after exposure. MSKCC's Contour software was used for dosimetric analysis. **Results:** EBT provided better intensity linearity with dose than EDR2 and higher pixel values in the clinical dose range. The pixel values of the EBT film differed by 3-9% (Epson) and 11-19% (Vidar) when rotating the film 90 degrees on the scanner, which resulted in up to 30% dose errors when mixing directions of IMRT and calibration films. The Vidar produced lower pixel values but higher optical density than the Epson. Calibration curves based on small films cut from one sheet coincided with the curves created from a set of sheets. EBT film IMRT dose distributions agreed well with EDR2 (1.9% on CAX for the Vidar, 3.6% for the Epson). **Conclusion:** GafChromic EBT film provides a good alternative for absolute IMRT dosimetry. Both film scanners provide equivalent dosimetric results. Calibration films and IMRT films have to be scanned in the same direction. The calibration curve can be created using small films cut from one large film. **Conflict of Interest:** Partial material support provided by ISP Corporation.

TH-C-T-6E-06

Evaluation of the TomoTherapy Planning Station Heterogeneity Correction Algorithm Using An Anthropomorphic Phantom

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Purpose: To evaluate the accuracy of the TomoTherapy Planning Station's heterogeneity correction algorithm using an anthropomorphic lung phantom. **Method and Materials:** The Radiological Physics Center's anthropomorphic lung phantom was imaged and then planned using the TomoTherapy Planning Station version 2.1.0.200. The water-filled phantom is comprised of a plastic shell containing two lung- equivalent structures, a heart structure and a spinal cord. The dosimeters were TLD located in the target and radiochromic film located in the 3 major planes passing through the center of the target. A median dose of 10 Gy was prescribed to the target with a helical delivery technique employing a field length of 2.5 cm. **Results:** The average TLD/planning system dose ratio in the center of the target was 0.980 ± 0.008. The dose to the target from the MVCT scan was only 1.05 cGy per scan. The radiochromic film was normalized to the TLD dose in the center of the target. The dose profiles within the target were in agreement with the plan. The preliminary results showed agreement throughout much of the irradiated volume, although the delivered dose was less than the planned dose in the superior and medial directions. **Conclusion:** The TomoTherapy Planning Station's heterogeneity algorithm calculated dose accurately inside a target centered in lung. Discrepancies were found in the dose calculated to the surrounding lung material resulting in an underdose.

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TH-C-T-6E-07

Analyzing the Accuracy of IMRT Dose Distributions Using a Dose Uncertainty Model

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Purpose: To provide dose verification methodology using a novel dose uncertainty model. **Method and Materials:** The expected value for an experimentally measured dose, $D(\vec{r})$ in space $\vec{r}$ can be expressed by $D(\vec{r}) = D_c(\vec{r}) \pm k \cdot \sigma(\vec{r}) + \varepsilon$ where $D_c(\vec{r})$ is the calculated dose distribution, k is the constant for confidence level, $\sigma(\vec{r})$ is the standard deviation (Gaussian distribution), and ε is the adjustable errors. The standard deviation is assumed to be a quadratic sum of the non-spatial and the spatial dose uncertainties. The product of the standard deviation and the confidence level k can be used as a tolerance bound for dose verification. The proposed model was verified using a Head and Neck IMRT treatment plan. Three-dimensional dose distributions from a total of 34 beam segments were extracted and a dose uncertainty map was computed to obtain the dose bound. EDR2 film was placed at the depth of 6 cm in solid water phantom to experimentally measure a dose distribution. The absolute difference between the measured and the calculated dose was compared with the dose bound using published dose comparison tools. **Results:** The dose bound was found to be large at the high gradient regions and small at low dose gradient regions. Using 95% (k=1.96) and 99.74% (k=3) confidence level, the acceptance test criterion passed 98.7% and 99.89% of the IMRT fields respectively. Most of the failures were in the high gradient regions. **Conclusion:** The proposed methodology is ideal for analyzing expected dose variations in IMRT fields that have contributions from high and low dose gradients of multiple subfields. None of the existing methodologies explicitly account for the spatial and non-spatial dose uncertainties. Most of these methodologies apply a single set of passive criterion. Our uncertainty model provides space-dependent tolerance level for comparison with the prediction of space-specific dose uncertainties.

TH-C-T-6E-08

High Resolution Film Based Finite Pencil Beam Model for MLC Defined Beamlets

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Purpose: We studied the detailed behavior of leaf-side and leaf-end multileaf collimator (MLC) defined beamlets with high spatial resolution film dosimetry. It is demonstrated that a simple analytic finite sized pencil beam model can be developed to accurately describe jaw-defined and MLC-defined small beamlet dose to water as a function of off-axis distance. Such a model has great utility in rapid IMRT delivery validation and fluence map optimization dose computations. **Method and Materials:** Kodak EDR2 was used to measure central and off-axis 1x1 cm2 beamlets from a Varian 2100 C/D linear accelerator using a 120-leaf Millennium MLC. Scanned images were imported into Matlab v7.0 for analysis. Horizontal profiles in both the leaf end and leaf side directions were normalized to fractional depth dose (FDD), corrected to remove beam divergence, and fitted with a sum of difference of error functions. Fit parameters were used in a FSPB model to calculate doses in 3D. **Results:** We found that leaf end and leaf side profiles remain approximately constant with depth when normalized to FDD and beam divergence. Off-axis profiles could be approximated by linearly scaling central axis profiles. The 20-80% lateral profile penumbral distances were found to be 0.21, 0.24, and 0.25 for leaf side MLC, jaw aperture, and leaf end MLC beamlets, respectively. **Conclusion:** A single FSPB dose calculation model agrees well with measured dose to water values in the leaf end and leaf side directions for both central and off-axis beamlets. The 20-80% lateral profile penumbral distances measured in this study are significantly smaller than those determined with micro-ionization chambers.

TH-C-T-6E-09

Multi-Leaf-Collimator Quality Assurance Using the Electronic Portal Imaging Device

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Purpose: To test the amorphous silicon (aSi) electronic portal imaging device (EPID) for quality assurance (QA) of the multi-leaf collimators (MLC) and to validate its use as a dynamic intensity-modulated radiation therapy (IMRT) QA device. **Method and Materials:** Established MLC QA for IMRT utilizes dosimetric outputs from a single point in phantom with a chamber, and radiographic film to capture the density-pattern of the MLC. We propose using the aSi EPID 2D-density distribution to replace the chamber/film for MLC QA, and to verify the dosimetry and mechanics of the MLC for IMRT. A protocol was developed to acquire QA data from the aSi EPID to provide tests for high dose gradients, average output doses, mechanical leaf stability, speed and positioning. The effects of various EPID exposed areas (2×2, 4×4, 6×6 cm^2) were used for intercomparison measurements with ion chamber and film. **Results:** Radiographic film output at gantry angle 270^o relative to 0^o varies by less than 2%, while the film measurements at other gantry/collimator angles agree within 1% with the ionization chamber. For the same conditions, EPID outputs vary by 1%-5% depending upon exposed area. Output variations may be due to mechanical shifts, gantry and EPID sag, or MLC drifts due to gravity. Minimizing these effects is under further investigation. **Conclusion:** A method has been developed to utilize the aSi EPID for MLC QA. The 2D density distributions of the EPID offer the potential for more quantitative analysis, and this procedure can be integrated into a routine program for comprehensive dynamic MLC-based IMRT and EPID QA. **Conflict of Interest:** This work supported in-part by Varian Medical Systems.

TH-C-T-6E-10

The Impact of Calculation Grid Size On the Accuracy of IMRT Dose Distribution

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Purpose: To experimentally investigate the accuracy of complex IMRT dose distribution with varying dose grid size. **Method and Materials:** A Head and Neck compression film phantom was constructed from two semi-hemisphere solid water slabs. Two hypothetical Head and Neck IMRT treatment plans for a 54Gy prescribed dose to a shallow and a deep targets were generated using Philips Pinnacle^3 TPS with 1.5, 2, 3, and 4 mm dose computation grid sizes. Radiochromic films were used for dosimetry. The plans were evaluated by computing the dose cumulative histograms. The 1.5 mm grid size plan was used as a benchmark for plan evaluation. **Results:** Dose differences between 2 mm and 1.5 mm grid size calculations were within 120 cGy (2.2% of prescribed dose) for shallow target and 132 cGy (2.4%) for deep target respectively over 95% of the area of analysis. The dose differences were 273 cGy (5.1%) and 253 cGy (4.7%) for the 4 mm grid size. In gamma function tests, all grid sizes met the criteria of acceptability (i.e., 95% of the region resulted in gamma index less or equal to 1 with a 3% dose difference and a 3 mm DTA criteria) except for deep target and 3 and 4 mm grid sizes. It was observed that larger grid spacing produces higher dose gradient, which contributes to the failure of the gamma test. The analyses of surface dose histograms showed a general trend of larger grid size producing broader histogram for surface dose. All grid spacing overestimate surface dose. **Conclusion:** Overall, the effect of varying grid size on dose variation appears to be insignificant as long as the grid size is less than 4 mm. However, 2 mm is recommended to ensure acceptable dose calculations, especially in high gradient regions.

Workshop — Room 608

Grantsmanship Workshop

TH-C-W-608-01

Grantsmanship Workshop

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The workshop on grantsmanship will cover the required elements for writing a successful grant. Speakers will discuss the NIH grant review process, what reviewers look for, and how to get one's ideas across to the reviewers. There will be a focus on important strategies that successful grantees use in the grant preparation process and common mistakes in NIH grant applications to avoid. Following speaker presentations, a panel discussion will be held.