2429 Monte Carlo Calculation of Dose to Spinal Structures from Intrathecally Administered Yittrium-90

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Purpose/Objective: The treatment of cerebrospinal fluid (CSF) malignancies by intrathecal administration of Iodine-131 radiolabeled monoclonal antibodies has been previously studied. Based on the assumption that more healthy tissue will be spared when a pure beta-emitter is employed, Yittrium-90 has been proposed as a preferable radioimmunoconjugate to I-131. It is believed that the shorter range of beta particles will offer better localization of the dose to metastases found within the subarachnoid space. However, such assumptions have not been accurately verified and validated. The purpose of this study is to quantitatively evaluate the dose distribution to the CSF space and its surrounding spinal structures following intrathecal administration of Y-90 based upon Monte Carlo modeling of the Y-90 source coupled with a 3-D digital phantom of a region of the spinal cord.

Materials/Methods: A 3-D digital phantom of a section of the T-spine was constructed from the Visible Human Project series of images. The original color photographs of the female cadaver were used to produce an 8-bit gray-scale series of images. This series of images was further processed so that only certain anatomical features of interest were represented. These features of interest include the spinal cord, central canal, subarachnoid space, pia mater, arachnoid, dura mater, vertebral bone, and intervertebral disc. Monte Carlo N-Particle (MCNP) version 4C was used to model the Y-90 radiation distribution. The size of the cells modeled with MCNP was made to coincide with the voxel size of the 3-D phantom. A set of images of just the CSF compartment was convolved with the radiation distribution obtained from the MCNP calculations to determine the dose distribution within the subarachnoid space and surrounding tissues. A fast Fourier transform (FFT) was utilized to transform the two sets of data into frequency space where they were multiplied together. The inverse Fourier transform was performed on their product in frequency space to obtain the convolution. The cumulated activity of Y-90 in the CSF compartment was calculated based on previously-published I-131 pharmacokinetic biodistribution data to obtain the overall dose due to the presence of Y-90 in the CSF.

Results: Dose calculations show that a significant dose is delivered to the subarachnoid space compared to the surrounding structures including vital tissues such as the spinal cord and bone marrow. Specifically, the average doses to tissues in Gy per mCi of initial activity are calculated to be: subarachnoid space = 1.4; central canal = 0.9; spinal cord = 0.6; pia mater = 0.9; arachnoid = 0.6; dura mater = 0.3. The vertebral bone (including marrow) and disc receive <0.02 and <0.005 Gy/mCi respectively.

Conclusions: Monte Carlo dose distribution calculations confirm that Y-90 delivers localized radiation dose, which is confined largely to the subarachnoid space as compared to the surrounding vital tissues. Based upon our dose distribution calculations, Y-90 is well suited for the treatment of CSF malignancies.

2430 Brachytherapy Seed Reconstruction from Fluoroscopic Images Using Network Flow Algorithms

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Purpose/Objective: Majority of medical practitioners use C-arm fluoroscopy in transrectal ultrasound (TRUS) guided prostate brachytherapy, but only in a qualitative manner. The ability to register the implanted seeds (that are visible in fluoroscope) to soft tissue anatomy (that is visible in TRUS) intra-operatively will allow us to make immediate provisions for dosimetric deviations from the optimal implant plan. The three major obstacles we face are: (a) discerning the 3D pose of the fluoro images, (b) registering fluoro space to TRUS space, and (c) reconstruct the position of seeds from multiple fluoro images. We have addressed the first two issues by a novel external fiducial structure [Jain et al, submitted AAPM 2004]. The missing link, intra-operative seed reconstruction from C-arm fluoroscope images, is addressed here.

Materials/Methods: A brute-force formalization of the seed-matching problem results in a high complexity search space which is of the order of 10^{150} and 10^{300} for 2 and 3 fluoroscopic images respectively. Hence previously proposed seed-matching approaches have predominantly been heuristic explorations of the search space [Todor *et al*, PMB 2002:47; Narayanan *et al*, Med. Phy. 2002:29; Tubic *et el*, Med. Phy. 2001:28; Su *et al*, MICCAI 2003], with no theoretical assurance on the accuracy of the answer. We convert seed-matching to a specific form of combinatorial optimization. Our formulation has many salient features: (a) exact solutions studied extensively by computer science community, (b) performance claims on the space-time complexity of the algorithm, (c) optimality bounds on the final solution, (d) guaranteed existence of a polynomial time solution for the global minima for seed-matching from 2 images, (e) proof of the non-existence of a polynomial time solution in case of more than 2 images, (f) derivation of a practical solution that can work near polynomial time on any number of images. A network flow formulation is used to model the seed-matching problem, where any flow in the network would represent a seed-matching, the desired solution being the flow with minimum cost. Primal-dual algorithms to solve such min-cost flow problems have been known from the literature. Furthermore, the min-cost flow problem for the case of 2 and 3 fluoroscope images reduces to the bipartite and tripartite matching problems, which have fast implementations available.

Results: Although 2 images had been known to be insufficient for seed reconstruction, the amount of inherent error was not known, the analysis of which became possible with our polynomial-time algorithm. A third image renders a generic reconstruction problem to be of non-polynomial complexity, yet we solved it in near polynomial time utilizing its special structure. Table 1(table 1) shows performance on synthetic data, where neighboring seeds are separated by 1cm within a volume of $5 \times 3 \times 3$cm. The inherent imprecision in the two-image case is indicated by the low back-projection error and high reconstruction error for the unmatched seeds, which is adequately resolved with a third image. Note that in the case of overlapping seeds, any flip in the matching though counted as erroneous, still reconstructs the seeds in the correct 3D locations. Runtime for most cases was under a minute on a PC (900MHz, 512MB RAM) running Matlab on Windows 2000.

Conclusions: The network flow approach appears to be sufficiently robust and fast on synthetic data for a large number of implanted seeds. The algorithm is being perfected to increase robustness to noise and accommodate for seed orientation.

Experimental validation is currently being carried out using a precision machined mechanical phantom, in which seeds can be placed at various a priory known positions. Further results would be made available during the conference.

Table 1: Seed Reconstruction Accuracy	**With 2 Images**					**With 3 Images**				
Number of seeds	**60**	**80**	**100**	**120**	**150**	**60**	**80**	**100**	**120**	**150**
Matching rate [%]	87.2	92.1	78.7	85.6	80.4	100.0	100.0	97.0	99.4	97.1
3D Reconstruction Error [mm] – matched seeds	0.18	0.18	0.17	0.18	0.18	0.07	0.07	0.07	0.07	0.07
3D Reconstruction Error [mm] – unmatched seeds	55.6	53.7	47.5	33.7	45.3	-	-	1.2	0.6	7.6
2D Back-Projection Error [mm] – unmatched seeds	13.5	13.2	11.7	8.2	11.1	-	-	0.8	0.9	8.0

2431 Intraoperative Detection of Seeds Through a Combination of Ultrasound and Two Radiographic Films in LDR Prostate Brachytherapy

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Purpose/Objective: Discrepancies between the planned seed positions and the locations of the seeds that are actually deposited in the prostate are unavoidable. There is a need to minimize the effects of these discrepancies in order to keep the delivered dose as close as possible to the planned dose. Thus, intraoperative localization of the deposited seeds is necessary, based on which, the treatment plan could be modified to determine new positions for the rest of the (yet unimplanted) seeds. Since treatment planning is generally based on transrectal ultrasound, it is of interest to explore this modality for intraoperative seed detection. One approach to seed detection in ultrasound is the use of parameters/features (such as statistical moments, texture analysis, gradient and median) that can discriminate a seed from the background/surrounding tissue in the B-mode image. However, due to the inherent random nature of ultrasonic B-scan images, detection of *all* the seeds *without any* false positives within an accuracy of ± 2mm (which is an essential requirement for intraoperative dynamic dosimetry to be implemented) is not a trivial task. Since seed insertion is performed under fluoroscopic guidance where all the seeds are generally visible, it may be possible to exploit such images for the detection of *all* the seeds *with no* false positives. The results of a feasibility study are described.

Materials/Methods: Transverse B-mode images of a tissue-mimicking phantom (CIRS) containing 75 dummy seeds were acquired at 1 mm intervals at a center frequency of 6.5 MHz. Since the length of a seed is 4.5 mm and the transverse focal beam width is 2 mm, a seed is typically observed on 6–7 consecutive transverse B-mode images. Two radiographic films of the phantom were obtained simultaneously in the simulator at ± 10 degrees. Each seed on a given film corresponds to one and only one 'true seed'in the respective B-mode image. In order to determine the location of this seed in the corresponding B-mode image, we identify candidates for seed pairs on each film and backproject them into the ultrasound volume. The intersections of the backprojected lines define positions where the actual seeds must reside. When several such intersections show a (potential) seed trace, the parameters/features described above for seed discrimination are used to identify the true seed.

Results: Given the positions of where the actual seeds must lay in the corresponding ultrasonic B-mode images, parameters based on moments, texture analysis, gradient and median were utilized to detect the seeds within ± 1mm–2mm of the given position in the B-mode image, and also within ± 3 mm intervals of the given position (essentially searching for the seed in 6–7 consecutive images within ± 1mm–2mm). Through a combination of two films and transverse ultrasonic B-mode images, all the 75 seeds in the tissue-mimicking phantom were detected within an accuracy of ± 1.64 mm with no false positives. 54 seeds were detected within an interval of 0 mm of the backprojected seed location (essentially on the same B-mode image), 13 seeds were detected within an interval of ± 1 mm, 2 within an interval of ± 2 mm and 2 within an interval of ± 3 mm of the given location. However, one seed was detected within an interval of 4 mm. The figure below is the histogram of errors (in mm) for detecting all the 75 seeds in the B-mode images.

Conclusions: Detection of brachytherapy seeds in ultrasonic B-mode images may be feasible based on parameters/features typically exhibited by the seed. However, a combination of ultrasound and two radiographic films appears to ensure 100% seed detection at 0% false positive rate and therefore may hold promise for intraoperative dynamic dosimetry.

2432 A Comparison of Day 0 and Day 14 Post Implant Dosimetry; Differences in Degree of Prostate vs. Seed Shift Between Day 0 and Day 14 Correlate with the Change in D90 and V100

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Purpose/Objective: Changes in dosimetric endpoints (D90, V100) over time have been attributed to changes in prostate swelling. The hypothesis is that D90 declines in proportion to prostate swelling, and improves with resolution of swelling. To test this hypothesis we compared the change in D90 between day 0 and day 14 MRI based dosimetry.