Daiquan Chen
"Impact of metal artifact reduction in treatment planning: comparison of dose calculation algorithms"

Purpose: To systematically evaluate, both in phantom and patient, dosimetric differences obtained by applying a metal-artifact reduction (MAR) algorithm in CT for different treatment planning algorithms.

Method and Materials: Helical CTs were acquired for six phantom configurations and four patient cases (head and neck, bilateral hip prostheses, femur, humerus rods). MAR was applied to reconstructed images using Matlab (v7.8) integrated into Extended Brilliance Workspace research platform (Philips Healthcare, Cleveland, OH). Two Cerrobend rods were fabricated for CIRS thorax phantom to investigate interfaces and simulated clinical configurations. Dose was calculated on original and MAR-corrected CTs using Anisotropic Analytic Algorithm (AAA), Pencil Beam Convolution (PBC) in Eclipse, Pencil Beam Convolution (PBC-BL) and Monte Carlo (MC) algorithms in Brainlab, with and without heterogeneity correction. Dose matrices were evaluated. Statistics from the same regions of interest evaluated sensitivity and accuracy of algorithms between original and MAR-corrected CT images.

Results: In phantom, with heterogeneity correction off, no appreciable dose differences were observed between original and MAR-corrected CT images. Approximately -1.8% mean dose difference was observed between original and MAR-corrected scans for single Cerrobend rod interfaced with tissue-metal-bone when calculated with PBC-BL. For double Cerrobend configuration, metal-lung interfaces yielded -12.1% and -18.1% difference in mean dose for PBC-BL and MC, respectively. For the patient data, dose differences between the original and MAR-corrected CT scans could be substantial. With the exception of PBC in Eclipse, up to 8 +/- 24% mean dose differences were observed for the 3D conformal plans. The most substantial dosimetric change was revealed for the MAR-corrected bilateral hip prostheses scan, with 12 +/- 31% mean dose differences observed for MC implemented in Brainlab.

Conclusion: Dosimetric differences revealed between original and MAR corrected CT scans can be substantial. These results can be used to facilitate the implementation of MAR corrected images in treatment planning.

Conflict of interest: Previous metal artifact reduction algorithm research was sponsored in part by Philips Medical Systems.

Raminder Sandhu
"Evaluation of patient setup uncertainties and effect of IGRT shift tolerance"

This study quantified population setup error for head and neck (HN) patients using daily shift data. Results were compared to published data and evaluated to determine effects of an image-guided radiotherapy (IGRT) shift tolerance. Translational shifts from daily Tomotherapy MVCT registrations were retrospectively analyzed for 32 HN patients to characterize population systematic and random errors. At our clinic, a physicist and physician must review the image registration and setup for all patient shifts greater than 10mm. The effect of this IGRT tolerance on patient setup was evaluated by calculating population setup statistics and number of failed fractions (shifts outside 10mm) for patients before (n=22/fractions=606) and after (n=10/fractions=267) IGRT policy. Group mean and population systematic errors are 0.3±1.7mm(lateral), -1.1±2.1mm(longitudinal) and 4.9±2.0mm(vertical). Random errors are in the range of 1.8-2.5mm. Results are similar to published data for HN with ranges of 0.0-3.8mm in magnitude, with the exception of the vertical direction due to treatment couch sag from virtual to treatment isocenter and thermoplastic mask shrinkage between simulation and treatment. After IGRT policy implementation, population setup statistics for the group mean are similar, however systematic and random errors decreased to 0.1-1.5 mm. With a 10mm tolerance, 27/606(4.5%) fractions failed before and 2/267(0.8%) after policy implementation. This difference was statistically significant (χ^2-p=0.005). Based on the magnitude of setup errors for HN patients, a stricter policy of 5mm tolerance may be warranted. The systematic shift of ~5mm in the vertical direction may require a 1cm tolerance for the z-direction or systematic correction after the first fraction. The number of failed fractions for a 5mm tolerance is 161/606(26%) before and 15/267(5.6%) after policy implementation (χ^2-p<0.0001). This analysis indicates that our patient setup data is consistent with published studies for HN and use of an IGRT tolerance can improve setup further, particularly for random setup errors.

Joshua Kim
“Iterative image reconstruction algorithm for Tetrahedron Beam Computed Tomography (TBCT)”

Purpose: Tetrahedron Beam Computed Tomography (TBCT) circumvents some problems of cone beam CT (CBCT) such as excessive scatter and suboptimal detector performance but still shares the same approximate cone reconstruction artifacts that result from using the FDK algorithm. Iterative reconstruction algorithms have recently begun to be widely employed in diagnostic CT scanners in order to suppress noise and reduce imaging dose. In this study, we developed an iterative TBCT image reconstruction algorithm which is able to mitigate the cone beam reconstruction artifact as well as reduce image noise.

Material and Methods: For this study, the simultaneous algebraic reconstruction technique (SART) algorithm was employed as our iterative reconstruction algorithm. The projection matrix was calculated using a distance driven method. The developed algorithms were tested using both projections calculated from numerical phantoms and projections collected by the TBCT system using a physical phantom. Noise levels in reconstructed images were quantified, and the approximate image reconstruction artifact at larger cone angles was evaluated.

Results: The SART algorithm was able to reconstruct the noiseless phantom data comparably to the FDK algorithm. With noisy data, the iterative method was able to reduce noise levels 16-20% in regions throughout the images compared to the FDK method. Using both numerical and real projection data from our TBCT benchtop system, the SART algorithm was able to maintain a spatial resolution similar to the FDK algorithm. The cone artifact was also significantly reduced.

Conclusions: By suppressing noise and reducing the cone reconstruction artifact, the iterative SART algorithm further improves the image quality of the TBCT system. Due to its scatter rejection geometry and the use of high quality CT detectors, TBCT can achieve image quality very close to that of diagnostic CT.

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Cory Knill
"Updating a Familiar Clinical Tool: Including Structures in Gamma Index Calculations"

Purpose: A recent Medical Physics publication showed that current IMRT QA procedures are not sufficient to detect clinically important differences between planned and delivered dose distributions. The results of the publication were tested and a novel QA technique was developed to better correlate QA results and clinical dose deviations.

Materials and Methods: Five treatment machines were created in the Varian Eclipse platform. The original machine used Varian golden beam data. Deviations, representing dose deviations, were introduced in the remaining machines by modifying MLC transmission factors and smoothing beam penumbras. Doses for 9 Head and Neck dynamic IMRT plans were calculated, creating 36 modified and 9 original plans. Maximum spinal cord dose and dose to 95% of the PTV (PTV-95%) were calculated. Modified plans were compared to originals with a gamma analysis commonly used in IMRT QA. A new method of gamma analysis was performed with author-developed software that used cord and PTV structures to vary the gamma passing criteria (%/mm) in proportion to the thickness of the structures that each beam traveled through. Pearson correlation coefficients(r-values) comparing the PTV-95%/spine dose differences and the gamma pass rates were calculated.

Results: Pearson coefficients for the max cord dose were -0.717/-0.720/-.750 for traditional 3/2/1(%/mm) passing criteria, respectively. This improved to -0.831 when using the structure dependent passing criteria. Pearson coefficients for PTV-95% were -0.729/-0.703/-.711 for the 3/2/1(%/mm) criteria and improved to -0.812 for the structure dependent criteria.

Conclusion: Unlike the results of the Medical Physics Publication, the calculations show a strong correlation between IMRT QA results and clinical dose deviations. In addition, incorporating planning structures into the gamma analysis improves the ability of the IMRT QA procedure to detect clinical dose deviations.

Troy Long

"Sensitivity Analysis for Lexicographic Ordering in Radiation Therapy Treatment Planning"

Purpose: To efficiently identify and calculate significant tradeoffs between structures in lexicographic IMRT and to present these relationships in a manner beneficial to physicians.

Methods and Materials: A lexicographic optimization (LO) approach to IMRT, where physicians categorize treatment goals by importance, partitions the treatment planning decisions into a multi-stage treatment planning model. However, since the objectives optimized in the different stages do not necessarily represent a strict prioritization, the impact of deviations from optimality in one stage may provide benefits in a later stage that are of interest to physicians. In order to identify significant benefits, we studied the tradeoffs in a prostate cancer case using an LO approach. Linear approximations of Equivalent Uniform Dose (EUD) that are convex combinations of mean dose and minimum or maximum dose were used as treatment plan evaluation criteria in both aperture- and beamlet-based models.

Results: Significant improvements to the treatment plan were found by examination of the inter-stage tradeoffs. For example, reducing the EUD to the PTV by less than 0.2 Gy from its maximum value, with respect to overall dosing restrictions, allows the EUD to the rectum to be lowered by more than 3.7 Gy. For each stage, charts were created showing the Pareto-efficient tradeoff between relaxing the previous stage and the current stage benefits, allowing physicians to make better-informed planning decisions.

Conclusions: This work highlights the benefits of a LO approach to IMRT treatment planning. Highly advantageous alterations to current treatment plans can be easily missed without a form of efficient sensitivity analysis on the treatment planning models. LO implicitly restrict attention to a subset of the Pareto efficient frontier that the physicians have deemed most important through the LO setup. This LO sensitivity analysis approach will be further developed and extended to other treatment sites

Kelly Younge
"Planning Constraints for Paraspinal Volumetric Arc Therapy"

Purpose: Inversely planned apertures for paraspinal radiotherapy have the potential to become irregular when constrained by only individual leaf gap or aperture area. We present progress toward the design and implementation of a cost function metric to penalize the creation of small, irregular beam apertures with questionable dosimetric accuracy.

Methods and Materials: We have planned several VMAT paraspinal cases using field weight and direct aperture optimization. Using film and scanning methods for dosimetry, calculational errors for typical paraspinal fields were quantified. Based on this data, a variety of aperture complexity metrics were designed and analyzed to determine which metric could best predict the dosimetric error. The most promising metric could then be constrained during inverse planning with the goal of reducing potential dosimetric uncertainty.

Results: Film dosimetry shows typical beam apertures generated by the planning system for VMAT paraspinal treatments can have mean errors up to 25% because of their small size and irregular shape. Errors are primarily found at aperture edges. Metrics that characterize the aperture shape, including an aperture erosion method and the average leaf position variation have shown promise. Additional metrics are under investigation.

Conclusions: Because of the large amount of uncertainty in the dosimetry for typical VMAT paraspinal fields generated during direct aperture optimization, it is necessary to have a method to estimate the total error in the plan, and thus build in a planning constraint that will reduce this error. This will help the planning system to produce results that are more likely to be viable treatment plans. Using measurement data that quantifies dosimetric error for planned beam apertures, we have designed and analyzed a variety of metrics to predict such errors. In future work we will generate paraspinal VMAT treatment plans with and without our metric and compare resulting plan quality and dosimetric errors.

Sean Boyer
"Using Breast Density as An Indicator of Side Effects and Change Induced by Tamoxifen and Radiation Treatment for Ductal Carcinoma in Situ"

Title: Using Breast Density as An Indicator of Side Effects and Change Induced by Tamoxifen and Radiation Treatment for Ductal Carcinoma in Situ

Purpose: Breast cancer kills more women in the United States than any other cancer except for lung cancer. Treatment is generally surgery followed by radiation therapy, chemotherapy and/or hormonal therapy. Many of these patients will have side effects to the treatment, including 80% of patients receiving radiation therapy, where 48% will have long term effects. The purpose of this paper is to identify if tracking breast density through treatment is possible, and if that breast density is indicative of side effects.

Methods: Patient data were acquired from patients recruited into ongoing studies in accord with a Karmanos Cancer Institute and Wayne State University approved research protocol. Patients were selected if they exhibited a suspicious mass after mammography and/or follow-up ultrasound. We tracked the patient volume-averaged breast density throughout the course of treatment, starting on the first day of treatment. We recorded the volume-averaged breast density of each breast generally once every week. To analyze this data, we plot the left and right volume-averaged breast density to determine if and how the breast density is changing. We used excel to determine the slope (the change of volume-averaged breast density in km/s vs. time in s) and the coefficient of determination (r^2) for our data.

Results: Our results show that the change in breast density over the course of radiation treatment, Tamoxifen treatment, and a combination of the two, is measureable.

Conclusions: We can detect a small change in breast density, in-vivo, on a weekly basis, throughout the course of treatment. The limitation to this study is the small number of patients, in this study only 5. Future studies are needed to determine the significance of our results. Currently, we believe that edema, and possibly fibrosis would be observable, which will be shown in future studies.