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3278

Density Overrides that Best Predict Bowel Changes during Pencil Beam Scanning Proton Radiotherapy for Prostate Cancer

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Purpose/Objective(s): Changes in patient anatomy during pencil beam scanning proton radiotherapy (PBSPT) can result in substantial differences in dose distribution. In patients with prostate cancer receiving elective nodal irradiation (ENI), interfraction variability in bowel position or bowel filling can highlight this uncertainty. Such changes are often managed by assessing the plan on CT dataset copies with the bowel contour overridden to other densities. The ideal Hounsfield Unit (HU) overrides remain unclear, but extremes (HU=0 water and HU=-1000 air) are often utilized. The aim of the present study is to determine the bowel density overrides that are most predictive of bowel changes during a course of PBSPT.

Materials/Methods: Consecutive patients, from a single institution, receiving PBSPT with ENI for intact prostate cancer were retrospectively reviewed for the period between 10/2020-12/2021. Proton radiotherapy consisted of 50.4 Gy in 28 fractions to the pelvic lymph node stations with a simultaneous integrated boost to 70 Gy in 28 fractions to the prostate. Individually contoured loops of small bowel, large bowel, and rectum were overridden to HU of 0 to -1000 in 100 HU intervals. A bowel evaluation structure, consisting of a bowel bag cropped 3 cm away from the high-risk volume, was created; its dose volume histogram was reviewed; and values for the maximum point dose (Dmax), V105%, V45Gy, V20Gy were recorded for each plan. The dosimetry of bowel override plans were compared to the patient's Quality Assurance CT (QACT) scans. The bowel override plan which most closely matched the dosimetry of each QACT for each dosimetric parameter was determined, and the prevalence of closest prediction for each override value was tabulated.

Results: A total of 32 QACTs from 12 patients were included. For Dmax, HU=0, HU=-100, and HU=-700 predicted most accurately with 10 (31.3%), 5 (15.6%), and 4 (12.5%) closest predictions, respectively. For V105%, HU=-700 and HU=-1000 performed best with 6 (18.8%) and 7 (21.9%), respectively. For V45, HU=0 and HU=-500 predicted best with 13 (40.6%) and 5 (15.6%), respectively. For V20, HU=0, HU=-200, and HU=-600 predicted best with 18 (56.3%), 4 (12.5%), and 3 (9.4%), respectively. Overall, HU=0, -100, -600, -700, and -1000 predicted best with 42 (32.8%), 11 (8.6%), 10 (7.8%), 12 (9.4%), and 12 (9.4%) out of the 128 total dose metrics, respectively. This created a relative bimodal distribution with peaks in the 0 to -100 and -600 to -700 ranges. The nominal plan predicted best in 13 scenarios.

Conclusion: Bowel density override plans remain an important tool for assessment of PBSPT robustness to bowel filling changes throughout the course of therapy as the nominal CT relatively poorly predicts QACT dosimetry. The relatively bimodal distribution of accurate predictions in this study would suggest that the most predictive overrides would be HU∼0 and HU∼-650. Future investigation into multidataset robust optimization with these overrides to improve plan robustness is planned.

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3279

Robustness Evaluation for Proton Therapy with a Spirometry Based Deep Inhalation Breath Hold System

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Purpose/Objective(s): Deep inhalation breath hold (DIBH) treatment allows for greater sparing of healthy tissue by minimizing target motion due to respiration. However, the breath hold level achieved during simulation and throughout treatment is not perfectly reproducible. DIBH techniques such as spirometry define an allowed variation in the nominal breath hold level to facilitate treatment. This variation represents an uncertainty which must be incorporated into the robust evaluation which is essential in proton therapy treatment planning. The aim of this study is to evaluate the dosimetric impact of this uncertainty for DIBH patients treated with proton therapy using a spirometry system with visual feedback and to determine the ideal clinical workflow to ensure robustness.

Materials/Methods: A dedicated workflow involving simulation, treatment planning and quality assurance was developed and implemented in our clinic to assess the potential dosimetric impact of this uncertainty. The workflow involved a multi-scan simulation procedure in which patients were simulated under their nominal breath hold level and two additional breath hold levels at ± 100 mL tidal lung volume with respect to the nominal. This variation was chosen as it represents twice the allowed variation during treatment in order to be conservative. The additional scans were used to assess motion near the target and to determine the best techniques to be used during plan optimization to ensure robustness. In particular a 5 mm motion threshold was used by physics to recommend the use of simultaneous optimization across all three image sets. The final treatment plan was forward calculated on the additional image sets to guarantee robustness. Patient data, including on-treatment imaging and verification CT scans (QA-CT), were analyzed to assess plan robustness for 30 patients treated under this workflow over two years.

Results: Out of 30 DIBH patients treated under this workflow the simultaneous optimization tool was recommended in three cases but ultimately not utilized in planning at MD/dosimetry discretion balancing dose to OARs and robustness. All thirty patients passed the robust evaluation procedure and there were no cases for which QA-CT indicated a need to revise a treatment plan due to a variation in the breath hold level.

Conclusion: Our initial experience indicates that in proton therapy utilizing spirometry based DIBH with visual feedback the uncertainty associated with the variation in breath hold level does not have a significant dosimetric impact on plan robustness. Given these results, the decision was made to reduce the workload and simplify the workflow by eliminating the additional scans and utilizing a single breath hold level during simulation.

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3280

Intrafraction Prostate Motion Management during Dose-Escalated Linac-Based SBRT

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Purpose/Objective(s): This study reports the first clinical experience worldwide using a novel electromagnetic (EM) tracking device for intrafraction prostate motion management during dose-escalated Linac-based stereotactic body radiation therapy (SBRT).
Materials/Methods: Thirteen patients with organ-confined prostate cancer underwent dose-escalated SBRT using flattening filter-free (FFF) volumetric modulated arc therapy (VMAT). The prescribed dose was 40 Gy in 5 fractions or 38 Gy in 4 fractions. The EM tracking device consisted of an integrated Foley catheter with a transmitter. Patients were simulated and treated with a filled bladder and an empty rectum. Setup accuracy was achieved by ConeBeam-CT (CBCT) matching and the prostate motion was tracked during all the procedure. Treatment was interrupted when the signals exceeded a 2 mm threshold in any of the three spatial directions and, unless the offset was transient, target position was re-defined by repeating CBCT. Moreover, the displacements that would have occurred without any intrafraction organ motion management (i.e., no interruptions and repositionings) were simulated and analyzed.
Results: In 31 out of 56 monitored fractions (55%), no intervention was required to correct the target position as a result of an excessive displacement. In 25 (45%) a correction was mandated, but only in 10 (18%), the beam delivery was interrupted. Total treatment time lasted on average 10.2 minutes, 6.7 minutes for setup, and 3.5 minutes for beam delivery. The prostate was found inside the 2 mm threshold from its initial position in 96% of the treatment time, i.e., in 94% of the time during the setup, and in 98% during the delivery (beam on + interruptions). Without any intrafraction motion management, the overall mean treatment time and the mean delivery time would have been 6.9 minutes and 3.2 minutes, respectively. The prostate would have been found outside the tolerance in 8% of the total session time, in 4% of the time during the setup, and in 14% during the beam-on phase. The probability of motion > 2 mm in the lateral, longitudinal, and vertical direction after 5 minutes was 3.6% (2/56), 8.9% (5/56), and 14.3% (8/56), respectively. The predominant motion pattern was posterior with a mean motion ≤ 2 mm occurring within 10 minutes. Moreover, the analysis of the rotation angles from all patients showed a systematic rotation in the pitch axis which is absent in the yaw axis. Concurrently, the range and standard deviation of rotation angles were larger in the pitch axis.
Conclusion: EM real-time tracking was successfully implemented for intrafraction motion management during dose-escalated prostate SBRT. Results showed that most of the observed displacements were < 2 mm in any direction; however, there were a non-insignificant number of fractions with motion exceeding the predefined threshold, which would have otherwise gone undetected without intrafraction motion management.

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3281

Withdrawn

3282

Dosimetric Benefits with a Lower Energy Photon Beam in Stereotactic Radiosurgery

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Purpose/Objective(s): Stereotactic radiosurgery (SRS) relies on very small field sizes on the order of a few millimeters to ablate lesions and spare normal structures. Currently a 6 MV photon beam is most often utilized beam energy although there has been an interest in developing lower energy photon beams for stereotactic radiosurgery due to their sharper dose fall off. This study aims to find if there is a dosimetric benefit of using a lower energy photon beam over 6 MV photons for SRS.
Materials/Methods: A 2.5 MV is developed for imaging purpose and is available from a linear accelerator. Monte Carlo simulations were used to simulate both 2.5 MV and 6 MV beams and calculate dose distribution. The details of the incident beams including cone accessory were simulated, with calculated doses benchmarked against measurements. The dose comparison between using 6 MV and 2.5 MV beams were based on a realistic treatment plan for thalamotomy treatment.
Results: For the same target dose coverage, the dose fall off is significantly faster with 2.5 MV beams. Based on calculated 3D dose distributions for a realistic patient treatment plan using 21 arcs with 4 mm cone beams delivered 15000 cGy to the target, the DVH analysis showed the maximum doses to brainstem, chiasm, and optic nerves were 691 cGy (435 cGy), 266 cGy (135 cGy) and 103 cGy (38 cGy) for 6 MV (2.5 MV) beams respectively. The mean organ doses are 136 cGy (64 cGy), 155 cGy (66 cGy) and 51 cGy (19 cGy) to brain stem, Chiasm and optic nerves for 6 MV (2.5 MV) beams respectively.
Conclusion: The dose reductions to organs at risk (OARs) with 2.5 MV beams are very significant ranging from 37% maximum dose to brain stem to 50% mean dose to chiasm, optical nerves and eyes. The sharper dose fall-off with 2.5 MV beam reduced unintended doses to OARs while providing the same target dose coverage. A dosimetric advantage of using 2.5 MV has been observed for delivery of an extremely high dose with very small circular field in SRS.

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3283

FLASH-Enabled Proton SBRT/SRS via Simultaneous Dose and Dose Rate Optimization (SDDRO)

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Purpose/Objective(s): The availability of SBRT/SRS is often hindered by dose-limiting toxicities to organs at risk (OAR). This work investigates the clinical potential of FLASH-RT for improving high-dose sparing of OAR, to enable SBRT/SRS that could otherwise fail to meet dose constraints with CONV-RT.
Materials/Methods: CONV-RT (via Bragg peaks (BP)) and FLASH-RT (via transmission beams (TB)) are compared with pencil beam scanning proton therapy, i.e., CONV-RT planned with IMPT-BP, and FLASH-RT planned respectively with IMPT and SDDRO of TB. While IMPT only optimizes the dose distribution, SDDRO also optimizes the FLASH effect, i.e., to maximize the normal tissue volume receiving dose rate and dose thresholds pertinent to the FLASH effect, which was set to be 40Gy/s and 8Gy. The plan evaluation is based on the effective dose, i.e., the product of the physical dose and FLASH dose modifying factor, which was set to be 0.7 when normal tissues meet both dose rate and dose thresholds.
Results: CONV-RT (i.e., IMPT-BP) was compared with FLASH-RT (planned with IMPT and SDDRO respectively) for three clinical SBRT/SRS cases of lung, prostate, and brain. For fair comparison, all plans had the same clinical objectives and were after the same normalization of D95%=100% for PTV. The effective dose results are summarized in the table. (1) The CI values show that SDDRO had the best target dose conformality (note that 0.95 is optimal under D95%=100%). (2) The mean doses at PTV-10mm (10mm expansion of PTV) suggest that SDDRO had the fastest high-dose falloff for normal tissues adjacent to the target. (3) For the lung case, per RTOG 0618, the max dose constraint 27Gy for esophagus was only met by SDDRO (25Gy), not CONV-RT (35Gy) or IMPT (37Gy); the max dose constraint 30Gy for trachea and bronchus was substantially relaxed to 22Gy by SDDRO. (4) For the prostate case, SDDRO substantially decreased V32Gy to nearly 0cc. (5) For the brain case, compared to CONV-RT, SDDRO substantially decreased V12Gy from 44cc to 14cc; note that V12Gy$\leq$15cc is required to reduce the likelihood of symptomatic radiation necrosis per HyTEC reports.