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Higher-Precision Dose Calculation Algorithm AcurosXB Performance in Stereotactic Radiosurgery

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Abstract
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Abstract

Objectives:

Stereotactic radiosurgery (SRS) is a challenging scenario for dose calculation due to lack of charged particle equilibrium and sharp dose falloff for multiple small, dispersed treatment volumes. Historically, the analytical anisotropic algorithm (AAA) has been a standard treatment planning software (TPS) dose calculation algorithm for these cases, but it is limited in its rigor in accounting for electron transport and it does not account for the true elemental composition of the medium. AcurosXB (AXB), a linear Boltzmann Equation solver, is a newer TPS dose calculation algorithm that more rigorously accounts for electron transport and elemental composition. As AAA is being replaced by AXB for routine, non-SRS radiation treatments at Duke and in the field generally, in this study, we compare the performance of these algorithms for SRS planning to better assess whether SRS should also transition from AAA to AXB.

Methods:

18 single-isocenter multi-target (SIMT) SRS volumetric modulated arc therapy (VMAT), (154 targets total), 15 single-target VMAT, and 15 single-target dynamic conformal arc (DCA) plans previously prepared using AAA were recalculated with AXB leaving all other plan parameters unchanged. Mean dose to each target was recorded for both AAA and AXB and compared to the mean dose calculated using an independent Monte Carlo dose calculation algorithm (long considered the gold standard for dose calculation in radiation therapy) which had previously been rigorously commissioned as a verification calculation algorithm for SRS. Additionally, PTV size, distance from nearest bone, and distance from isocenter were recorded for each target for both techniques (VMAT and DCA).
QA verification deliveries were carried out for 28/154 (18.2%) SIMT VMAT targets and 3/15 (20%) DCA plans, with dose being calculated (for both AAA and AXB), delivered, and measured with a high-resolution diode array placed within an SRS QA phantom. Mean dose to the high dose region (80% of maximum dose measured) was compared between measurement and calculation. Four Gamma Index Passing Rates (GPR) of varying criteria (10%/50% threshold, 2%/3% dose difference, 1mm distance to agreement) were calculated for each measured target.
A linear regression model was created to describe the relationship between plan parameters (log(PTV size), distance from bone, distance from isocenter, and technique) and the TPS mean target dose difference from Monte Carlo. Separate models were created for AAA and AXB.

Results:

For the SIMT mean target dose calculated on patient anatomy, the difference between AAA and Monte Carlo was -3.0%±2.7% (mean±standard deviation), with a Root Mean Square (RMS) difference of 4.0%; for AXB the difference was -3.6%±1.7% (RMS=3.9%). The number of targets with mean dose outside a ±5% threshold was 32/154 for AAA and 25/154 for AXB. Regarding the agreement between AAA/AXB with measurements, average GPR was 99.3%±1.8% for AAA and 97.0%±4.26% for AXB (3%, 1mm, 50% threshold). Agreement in the high dose region was slightly better for AAA than for AXB (-0.6%±2.0% vs -1.6%±2.1%).
For the single target VMAT cases, the average target mean dose difference between AAA and Monte Carlo was 0.88%±0.93% (RMS=1.28%); for AXB the average mean difference was -0.43%±0.75% (RMS=0.87%). No target had a mean dose difference outside 5% for either dose calculation algorithm
For the DCA cases, AXB agreed better than AAA with Monte Carlo (Mean target dose difference: -0.03%±1.02% vs 1.64%±1.11%, RMS: 0.98% vs 1.96%) as well as the measurement mean dose difference in high dose region (1.8%±0.4% vs 3.4%±0.6%) and 3%, 1mm, 50% threshold GPR (100%±0% vs 95.6%±7.6%).

The regression model for AAA yielded fitting coefficients for log(PTV size) (p= 0.000392), distance from bone (p=0.000899), distance from isocenter (p=9.72E-5), and technique (p=0.016736) that were all significant (p< 0.05). Distance from isocenter was the regressor that the model most confidently predicts has an influence on mean dose difference with Monte Carlo. The AXB regression model only yielded a single significant coefficient for distance from isocenter (p=1.67E-11). Coefficients for distance from isocenter are -0.46%/cm for AAA and -0.55%/cm for AXB (maximum distance from isocenter 8.25 cm).

Conclusion(s):

Results were mixed on whether AAA or AXB had better performance. In comparison to Monte Carlo, for SIMT cases, AAA agreed better with Monte Carlo on average but had a larger variance than did AXB. AXB showed slightly better performance in all three metrics (average, standard deviation, and root mean squared mean target dose differences) for the single target VMAT and DCA cases evaluated but both AAA and AXB showed good agreement with Monte Carlo with 0 cases outside 5% dose difference. The two regression models show that the number of sources of error between the TPS dose calculation and Monte Carlo can be reduced if using AXB. Due to the small p-value in both models, distance from isocenter is very likely correlated with the difference between both TPS algorithms and Monte Carlo. We believe this is due to the limitations of the multi-leaf collimator (MLC) modeling used in the TPS algorithms. Future work will include evaluating AAA/AXB in conjunction with the newly released MLC model.