Evaluating an Enhanced MLC Leaf Model for LINAC-Based Stereotactic Radiosurgery

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Objectives: Linac-based stereotactic radiosurgery (SRS) has gained increasing popularity for managing brain metastasis due to the greater accessibility and high delivery efficiency from single-isocenter multiple-targets (SIMT) treatments. The small field condition and increasing modulation complexity of SIMT pose significant challenges to the modeling accuracy of multi-leaf collimator (MLC). In the current Eclipse (Varian Medical Systems, Palo Alto) treatment planning system, a binary MLC geometric model is used for dose calculation and the on- and off-axis penumbra approximation relies on a single tunable variable – the dosimetric leaf gap (DLG). For high precision SRS treatments, unsatisfactory agreement between measured and calculated doses is reported, and a trial-and-error tuning of DLG is often needed to minimize the difference, leading to increased commissioning complexity and user-dependent variability. In the latest version of Eclipse (v18), an enhanced MLC model is implemented by constructing the actual rounded leaf end design and calculate attenuation through ray tracing. We hypothesize that this enchanted leaf model leads to improved efficiency and accuracy of the enhanced leaf model (ELM) MLC and compare it against the regular DLG-based MLC model for Linac-based SRS.

Methods: Dose calculations using Analytical Anisotropic Algorithm (AAA) were performed in a test Eclipse v18 environment (AAA-18) under 10FFF energy. The original beam data from Eclipse v16 of an Edge linear accelerator equipped with HD-MLC were imported into the test system. The DLG for the original AAA-SRS-16 model was optimized for SRS treatments. The ELM parameters were configured with a set of open field, transmission, and varying leaf gaps and measured by solid water and a PTW N30004 farmer type ion chamber. A beam model named AAA-18 was constructed in the test system using ELM and same beam data from v16. The doses were re-calculated using the AAA-18, for (1) six static on-axis small fields from 0.5x0.5cm2 to 4x4cm2, (2) three single-isocenter single target (SIST) plans optimized by HyperArc technique (PTV volume 0.07cc to 0.9cc), (3) three SIMT HyperArc plans (PTV volume 0.12cc to 5.2cc, and PTV to isocenter distance from 1.6cm to 4cm). SRS MapCHECK was used for dose measurement and comparison between different MLC models.

Results: The time spent on ELM parameters measurement was comparable to the original MLC measurement. However substantial time saving was associated with the new ELM model configuration compared to original DLG method. In the original SRS dose calculation algorithm modeling, we re-tuned the DLG four times to find the value with acceptable agreement between calculation and measurement, while each round took hours for the re-calculation and re-evaluation.

However, the optimal DLG was still unknown due to the limited time we could spend during modeling. The ELM configuration was one-time implementation and only required one round of calculation and verification on the same dataset.

For 10FFF energy, AAA-18 demonstrated improved agreement with measurement compared to AAA-SRS-16. Using SRS MapCHECK, all plans achieved 99-100% gamma passing rate at 3%/1mm 10% threshold with either MLC model. For small static fields, SIST, and SIMT, the average 1%/1mm gamma passing rate were 93.5%, 98.4%, and 86.3% in the AAA-SRS-16 plans, and 97.5%, 99.5%, and 92.2% in the AAA-18 plans. The 0.5%/0.5mm passing rate was also improved in AAA-18.

Conclusion(s): The new enhanced leaf model introduced in Eclipse v18 substantially improves the efficiency and consistency of modeling process of the Eclipse dose calculation algorithm while maintaining comparable or superior accuracy for Linac-based SIST and SIMT SRS treatment applications.