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Dosimetric Validation of an Enhanced Leaf Model in Single Isocenter Multi Target Stereotactic Radiosurgery

Soyoung Lee, PhD[1]; Jinyu Xue, PhD[1], Jose R. Teruel, PhD[1], Zahid Ahmad Safi, MS[1], Paulina E. Galavis, PhD[1]
[1]NYU Langone Health

ABSTRACT

Purpose: To evaluate the accuracy of the Enhanced Leaf Model (ELM) implemented in Eclipse v18.0 for single-isocenter multiple-target (SIMT) stereotactic radiosurgery (SRS), with emphasis on updated MLC modeling and dosimetric precision.

Methods: A clinical ELM was implemented in Eclipse v18.0 for TrueBeam linac equipped with Millennium 120 MLC. Model validation was performed using several MLC test plans, including a 3 mm narrow MLC slit (nMLC) and dynamic MLC (dMLC) field with 3 mm sweeping gaps. GafChromic EBT4 film was used to compare the profiles with the MLC plans. Several SIMT plans originally calculated with a dosimetric leaf gap (DLG)-based MLC model in Eclipse v15.6 were recalculated using the ELM in v18.0. Dose calculations were performed with AAA for 6MV FFF.

Results: For 6MV FFF, MLC plan profiles calculated with the ELM were comparable to those with the DLG-based model. Overall agreement between calculated and measured MLC profiles was improved with ELM, presenting well matched low-dose penumbra region in the nMLC profile and shoulder region in dMLC profile, particularly in regions sensitive to MLC motion and leaf transmission associated with the updated leaf-tip modeling in ELM. In SIMT plans recalculated with the ELM, small reductions up to -4% in target coverage were observed for selected off-axis targets, which resulted from coverage shifts of up to approximately 0.2 mm, while overall dose differences remained minimal.

Conclusions: ELM provides improved dose modeling for MLC-defined fields. For very small targets, particularly located at off-axis, the combined impact of geometric uncertainties and subtle changes in MLC shoulder modeling may influence target coverage. These findings provide practical guidance for ELM implementation and highlight the importance of defining target size limits and selecting appropriate margins during SIMT SRS planning when using conventional DLG-based MLC model.

NYU Langone Health

CONTACT

Soyoung Lee
NYU Langone Health
160 E 34th St, New York, NY 10016
Soyoung.Lee@nyulangone.org
212-731-5883

INTRODUCTION

The Enhanced Leaf Model (ELM), introduced in Eclipse TPS v18.0 or later (Varian Medical Systems, Palo Alto, CA, USA), improves geometric representation of MLC leaf bodies and rounded leaf ends using divergent ray tracing, resulting in improved dose calculation accuracy. Additionally, the ELM has contributed to more efficient delivery of stereotactic treatments involving complex dynamic MLC movements, particularly for small targets located on- and off-axis.

The purpose of this study was to evaluate the accuracy of the ELM in v18.0 for single-isocenter multiple-target (SIMT) stereotactic radiosurgery (SRS), with emphasis on updated MLC modeling and dosimetric precision.

METHODS AND MATERIALS

A clinical ELM was implemented in Eclipse v18.0 for TrueBeam linac equipped with Millennium 120 MLC. Model validation was performed using several MLC test plans, including a 3 mm narrow MLC slit (nMLC) and dynamic MLC (dMLC) field with 3 mm sweeping gaps. Radiochromic EBT4 film was used to compare the measured and calculated dose profiles (in v15.6 and v18.0). A total of 43 targets (PTV = GTV + 1 mm) from 12 clinical SIMT SRS plans originally calculated with a dosimetric leaf gap (DLG)-based MLC model in Eclipse v15.6 were recalculated using the ELM in v18.0. The dose calculations were performed with AAA for 6MV FFF.

1) nMLC: A 3 mm MLC slit delivered at central axis (CAX), 5, 10, and 15 cm off-axis (OAX) to evaluate penumbra and small-aperture sensitivity to leaf gap variation.[1]
2) dMLC: A 2 cm field generated with overlapping 3-mm sweeping gaps was delivered at CAX, 4, 8, and 12 cm OAX.[1]

1) nMLC

2) dMLC

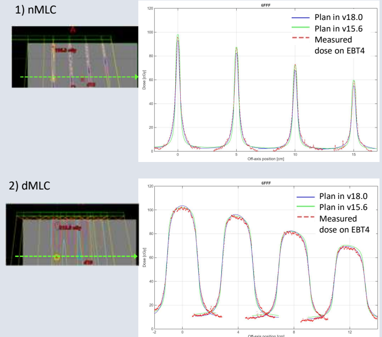

Figure 1. ELM Beam Validation on Radiochromic EBT4 film. The plan dose profiles calculated with v15.6 and v18.0 were compared with the measured dose profiles for 1)nMLC and 2) dMLC across the x-axis.

RESULTS

For 6MV FFF, the MLC plan profiles calculated with the ELM were comparable to those with the DLG-based model. Overall agreement between calculated and measured MLC profiles was improved with ELM, presenting well-matched low-dose penumbra region in the nMLC profile and shoulder region in dMLC profile, particularly in regions sensitive to MLC motion and leaf transmission associated with the updated leaf-tip modeling in ELM.

In the SIMT SRS plans recalculated with the ELM, small reductions up to -4% in PTV coverage were observed for selected off-axis targets, which resulted from coverage shifts of up to approximately 0.2 mm, while overall dose differences remained minimal.

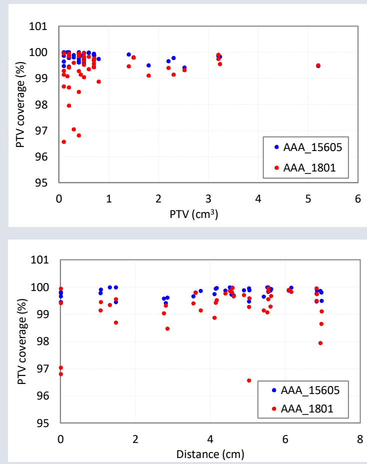

Figure 2. The PTV coverage comparison between the plans calculated with AAA in v15.6 and in v18.01 as a function of target volume (top) and distance (bottom).

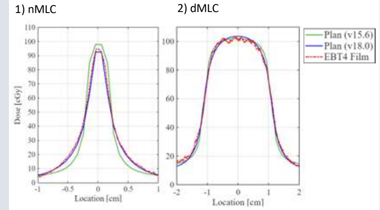

Figure 3. Comparison between the measured profiles and calculated profiles with DLG-based MLC model in v15.6 and ELM in v18.0 at CAX: 1) nMLC and 2) dMLC.

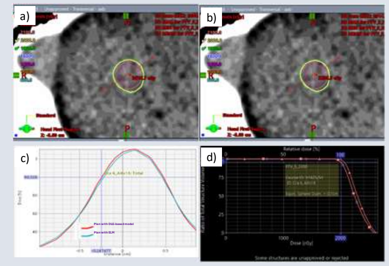

Figure 2. A target in 0.17 cm³ located at 4 cm from the isocenter SIMT SRS plan. (a) SIMT SRS plan calculated with the DLG-based MLC model, (b) Same MU was used, and recalculated with the ELM model. (c) dose profile comparison on the target, (d) PTV coverage difference in DVH: The 100% target coverage was 99.0% in the plan calculated with the DLG based MLC model, and 95.9% in the plan calculated with ELM.

DISCUSSION

When clinical SIMT SRS were recalculated with ELM, small reductions in target coverage were observed for several targets (Fig 2). These differences were consistent with subtle changes in shoulder modeling and resulted in dose fall-off reduced by approximately 0.2 mm, while overall dose differences remained minimal. The penumbra difference observed with ELM was limited to approximately 0.2 mm as SIMT SRS requires 3 to 5 non-coplanar beams and sub-millimeter accuracy, particularly for off-axis targets. These findings demonstrate the improved geometric accuracy of ELM dose calculations and suggest that residual modeling uncertainty associated with conventional DLG-based MLC modeling may influence target coverage for very small off-axis lesions.; this should be considered in margin selection when prior MLC models remain in clinical use before ELM upgrade.

CONCLUSIONS

- ELM provides improved dose modeling for MLC-defined fields, especially for very small off-axis targets.
- When conventional DLG-based MLC models are used (e.g., Eclipse v15.6), careful evaluation of target size limits and planning margins is recommended for SIMT SRS.

REFERENCES

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2. Varian Medical Systems, Inc. Enhanced Leaf Modeling Measurement Procedure, Document ID P1062983-002-B; Palo Alto, CA: Varian Medical Systems, Inc., 2023.