Analytical Modeling of the Parameters of a Multileaf Collimator for Monte Carlo Dose Simulations in Radiotherapy

JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]

J. C. Martins[1], S. Neppl[2], A. Alhazmi[1,4], J. Fleckenstein[3], G. Dedes[1], M. Reiner[2], C. Belka[2], K. Parodi[1], S. Veloza[1,5]

[1] Department of Medical Physics, Faculty of Physics, Ludwig-Maximilians-Universität München, Garching b. München, Germany
[2] Department of Radiation Oncology, University Hospital, LMU Munich, Munich, Germany
[3] Department of Radiation Oncology, Universitätsmedizin Mannheim, Medical Faculty Mannheim, University of Heidelberg, Mannheim, Germany
[4] Currently at: King Saud University Medical City, Riyadh, Saudi Arabia
[5] Currently at: Universidad Nacional de Colombia, Bogota, Colombia

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

INTRODUCTION

Monte Carlo (MC) techniques are considered the most accurate tool for simulating the dose deposited to heterogeneous media, and therefore their applicability in radiotherapy has greatly increased in the last decades [1]. However, the quality of the output depends on reproducing accurately the geometry of the machine, as well as the correct modelling of the initial electron beam incident on the target. The latter challenge can be overcome by using validated phase space files (PhSp) [2] or Virtual Source Models (VSM) [3].

AIM

A detailed geometric description of multi leaf collimator (MLC) systems is scarcely available and is often conditional to the sharing of confidential information from the vendors. This work proposes an analytical method to determine crucial geometric parameters for MC modelling of MLC systems, based only on information freely available in the literature.

METHOD

A in-house validated PhSp file was used as a replacement for the static part of the linear accelerator (linac). An extensive literature review was performed to collect available geometric parameters and general constraints for the Elekta Agility® MLC (Table 1). The gathered information was used to construct a MC model of the MLC and to define analytical expressions for the collimators' positions. Eq. 1 to 6 are the expressions for the leaves (similar expressions were developed for the diaphragms). Inter and intraleaf transmission simulations and measurements in a water phantom were used to find, iteratively, the best combination of leaf thickness, density and shift to virtual focus (virtual tongue and groove, vT&G). For validation, percentage depth dose (PDD), lateral profiles and the T&G effect were simulated and compared against measurements performed under the same conditions. 3D dose distributions in a cylindrical water-equivalent phantom (Octavius 4D®) were simulated and compared against calculations performed by a commissioned clinical treatment planning system (TPS), for several squared fields and one IMRT Head and Neck treatment plan. Validation in patient geometry is ongoing.

Parameter	Meaning	Value [4]
θ	Leaf's focusing angle, with respect to the central axis	Eq. 1
F_{max}	Maximum field size	400 mm
N_{leaf}	Number of leaf pairs	80
iso	Distance between target and isocenter	1000 mm
d_{leaf}	Distance from isocenter to leaf bank	356.8 mm
$d_{leaf-curv}$ '	Position of leaf curvature with respect to leaf center	7.5 mm
R '	Leaf's curvature radius	170 mm
F_{cross}	Leaf aperture with respect to isocenter	-
L	Leaf's length	155 mm
Pos_{cross}	Leaf's position in the crossline direction	Eq. 2
Pos_{in}	Leaf's position in the inline direction	Eq. 4
$Pos_{central}$	Inline position of the two central leaves with respect to isocenter	Eq. 5
$\theta_{central}$	Focusing angle of the central leaves	Eq. 1
γ	Leaf's side divergence	Eq. 6
W_d	Leaf's width down	1.91 mm
W_u	Leaf's width up	1.47 mm
h '	Leaf's height (tunable)	92* mm
Density	Material density of the tungsten alloy for leaves and diaphragms (tunable)	18.2* g/cm³

$$\theta = \frac{tan^{-1}\left(^{0.5F_{max}}/_{iso}\right)}{N_{leaf}-1} \quad \text{(Eq. 1)}$$

$$Pos_{cross} = \left(d_{leaf} - d_{leaf-curv} + Rsin\beta\right)\frac{F_{cross}}{iso} + Rcos\beta - (0.5L + d_{shift}) \quad \text{(Eq. 2)}$$

$$\beta = tan^{-1}\left(\frac{F_{cross}}{iso}\right) \quad \text{(Eq. 3)}$$

$$Pos_{in} = Pos_{central} + \sum_i \left\{\frac{\cos(\gamma)}{cos[\theta_{(i+1)}+\gamma]} + \frac{\cos(\gamma)}{cos[\theta_{(i)}-\gamma]}\right\} \quad \text{(Eq. 4)}$$

$$Pos_{central} = \frac{\cos(\gamma)}{cos[\theta_{central}-\gamma]} \quad \text{(Eq. 5)}$$

$$\gamma = tan^{-1}\left(\frac{0.5(W_d-W_u)}{h}\right) \quad \text{(Eq. 6)}$$

Table 1: Example of leaves' parameters and respective values, either gathered from literature, or calculated using Eq. 1 to 6. Similar information was found for the perpendicular diaphragms. Values marked with * correspond to the initial input value, which were tuned to match the measurements. Parameters marked with ' can also be described by analytical expressions.

RESULTS

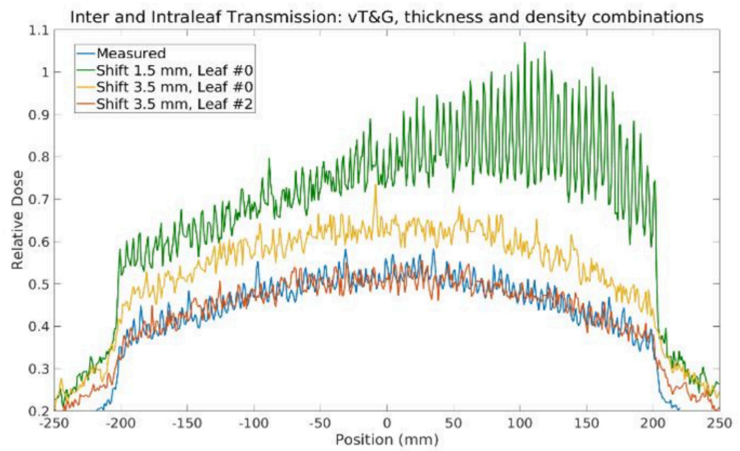

Figure 1: Inter and intraleaf transmission for different vT&G and leaf-thickness-density combinations. Leaf #0 corresponds to initial values, while Leaf #2 corresponds to tuned values. The measurements were performed in a water phantom using an ionization chamber.

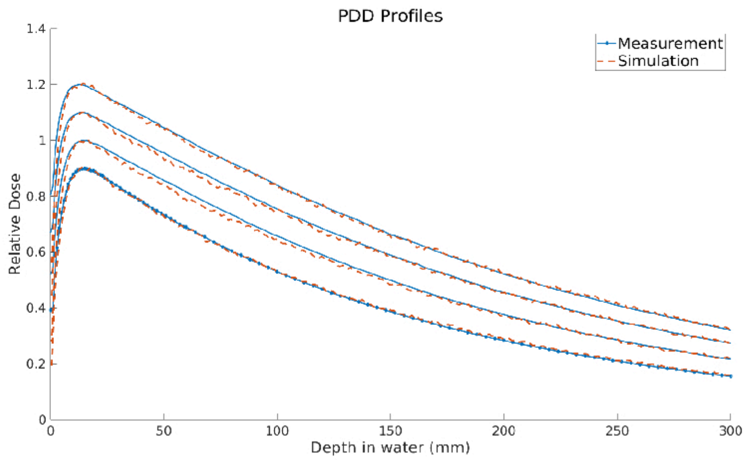

Figure 2: Measured and simulated PDD profiles for different squared fields, ranging from 2 x 2 cm² up to 30 x 30 cm². The measurements were performed in a water phantom with a micro diamond detector. The curves have been shifted vertically in pairs for better visualization.

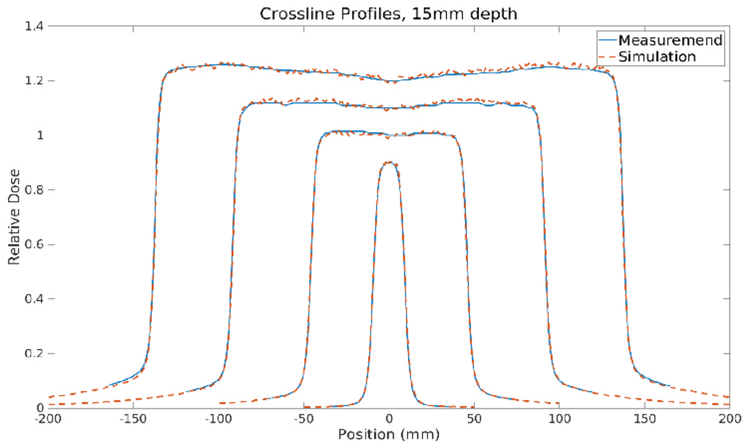

Figure 3: Measured and simulated crossline profiles for different squared fields, ranging from 2 x 2 cm² up to 30 x 30 cm². The measurements were performed in a water phantom with a micro diamond detector, at 15 mm depth in water. Similar results were obtained for inline profiles and at a depth of 100 mm. The curves have been shifted vertically in pairs for better visualization.

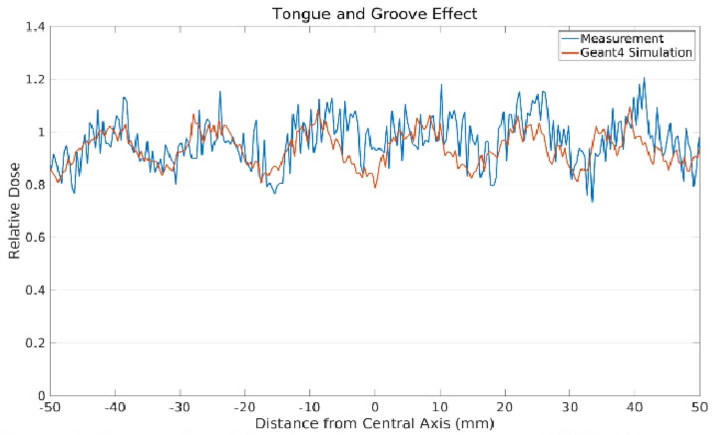

Figure 4: Measured and simulated tongue and groove (T&G) effect, using the picked-fence test. Measurements were performed using the Elekta iViewGT® EPID, installed in the linear accelerator used in this study. The curve shows the central region (100 mm wide) for better visualization of the T&G effect.

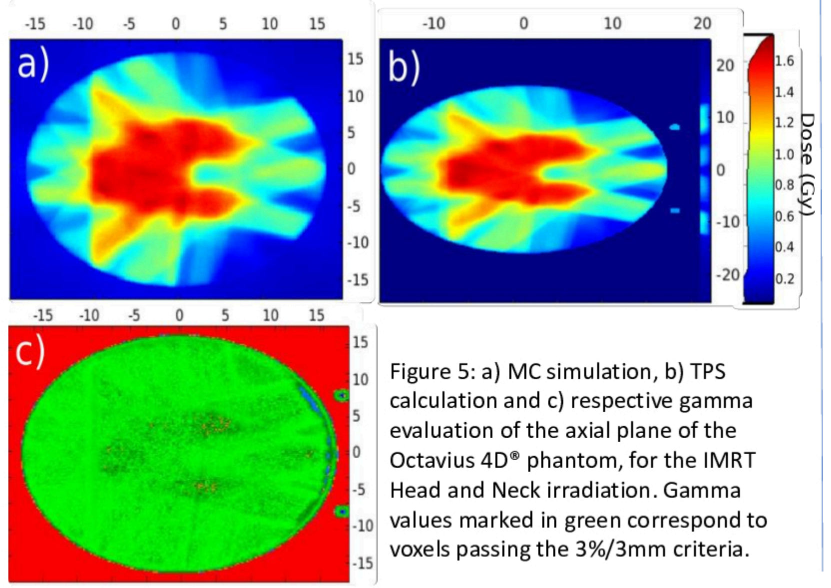

Figure 5: a) MC simulation, b) TPS calculation and c) respective gamma evaluation of the axial plane of the Octavius 4D® phantom, for the IMRT Head and Neck irradiation. Gamma values marked in green correspond to voxels passing the 3%/3mm criteria.

Table 2: The gamma evaluation method was performed to quantify the agreement between Monte Carlo-simulated and TPS-calculated 3D dose distributions. Gamma criteria used were set to: percentage dose difference (PD) of 3% and a distance-to-agreement (DTA) of 3 mm. The passing rate (percentage of voxels passing the PD and DTA criteria), for the different irradiations, are shown below. Only voxels positioned inside the phantom and scoring more than 25% of the maximum dose value were considered.

Geometry	Irradiation	Passing Rate (%)
Octavius	2 x 2 cm²	99.6
Octavius	2 x 2 cm²	96.6
Octavius	5 x 5 cm²	96.7
Octavius	10 x 10 cm²	97.2
Octavius	26 x 26 cm²	96.7
Octavius	IMRT Head and Neck	98.1

CONCLUSIONS

- Geometric information concerning MLC systems are hardly available. However, many parameters gathered from an extensive literature review can be used as initial inputs to build a Monte Carlo model of a MLC. Such parameters should be tuned to specific equipments.
- The parameters obtained by the analytical models can be used to produce reliable, equipment-specific geometric parameters for MC simulations without depending on vendor's confidential information.
- The methodology is validated for a specific linear accelerator model, but it is general and can be applied to any equipment.

REFERENCES

[1] Rogers, D. W. O. "Fifty years of Monte Carlo simulations for medical physics." *Physics in Medicine & Biology* 51.13 (2006): R287.

[2] Martins, J. C., Saxena, R., et al. "Optimization of Phase Space files from clinical linear accelerators." *Physica Medica* 64 (2019): 54-68.

[3] Nwankwo, O., et al. "A single-source photon source model of a linear accelerator for Monte Carlo dose calculation." *PloS one* 12.9 (2017): e0183486.

[4] The full literature references to the values listed in Table 1 can be provided upon request, by contacting the presenting author.

ACKNOWLEDGEMENTS

This work was supported by the Brazilian National Council for Scientific and Technological Development (CNPq, Grant No. 201383/2015-2); the Saudi Ministry of Education; the Alexander von Humboldt Foundation; and the Munich-Centre for Advanced Photonics (MAP). The authors thank Prof. Dr. Guillaume Landry, Dr. Chiara Gianoli and Dr. Mark Podesta for support and fruitful discussions.

CONTACT INFORMATION

Juliana Martins: Juliana.Martins@physik.uni-muenchen.de
Katia Parodi: Katia.Parodi@physik.uni-muenchen.de