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Multileaf collimator tongue-and-groove effect on depth and off-axis doses: A comparison of treatment planning data with measurements and Monte Carlo calculations

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ABSTRACT

To investigate how accurately treatment planning systems (TPSs) account for the tongue-and-groove (TG) effect, Monte Carlo (MC) simulations and radiochromic film (RCF) measurements were performed for comparison with TPS results. Two commercial TPSs computed the TG effect for Varian Millennium 120 multileaf collimator (MLC). The TG effect on off-axis dose profile at 3 depths of solid water was estimated as the maximum depth and the full width at half maximum (FWHM) of the dose dip at an interleaf position. When compared with the off-axis dose of open field, the maximum depth of the dose dip for MC and RCF ranged from 10.1% to 20.6%; the maximum depth of the dose dip gradually decreased by up to 8.7% with increasing depths of 1.5 to 10 cm and also by up to 4.1% with increasing off-axis distances of 0 to 13 cm. However, TPS results showed at most a 2.7% decrease for the same depth range and a negligible variation for the same off-axis distances. The FWHM of the dose dip was approximately 0.19 cm for MC and 0.17 cm for RCF, but 0.30 cm for Eclipse TPS and 0.45 cm for Pinnacle TPS. Accordingly, the integrated value of TG dose dip for TPS was larger than that for MC and RCF and almost invariant along the depths and off-axis distances. We concluded that the TG dependence on depth and off-axis doses shown in the MC and RCF results could not be appropriately modeled by the TPS versions in this study.

Introduction

The multileaf collimator (MLC) is a key component of modern intensity-modulated radiation therapy (IMRT). Early models of the MLC led to a serious interleaf leakage owing to a finite air gap between 2 adjacent leaves. To reduce the interleaf leakage, the leaf side was changed into a stair shape, so the tongue-and-groove (TG) geometry was formed. Although such an MLC design can diminish the interleaf leakage, it causes an underdosage at the interleaf position as the region between the adjacent leaves is always covered by the tongue or the groove or by both.[1,2] Several studies reported that the underdosage at an interleaf position of TG ranged from 10% to 28%.[3-8] The TG underdosage at an interleaf position for the Varian MLCs (80 and 120 MLCs) was reported at 10% to 25% in the literature,[4-6,8,9] while one for the Philips MLC ranged from 15% to 28%.[7] The maximum dose reduction reported by Agazaryan *et al.*[3] for the m_3 (BrainLAB AG, Heimstetten, Germany) MLC was 15%. Conversely, with improved leaf sequencing algorithms, the TG underdosage was reduced into 3% in certain cases.[2,10-12] Deng *et al.* also reported that the TG underdosage could lessen when more than 5 fields were used in the step-and-shoot IMRT.[4]

The advanced technology of radiation therapy often requires a heavy use of MLC and high accuracy of dose calculation. Thus, treatment planning systems (TPSs) have been developed by integrating technical details of MLC characteristics into their calculation and optimization algorithms. The MLC modeling parameters of TPS include MLC transmission, rounded leaf tip

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radius, MLC leaf position offset, TG width, and additional interleaf leakage transmission.[13-16] The Pinnacle TPS (Philips Radiation Oncology Systems, Milpitas, CA) has incorporated the aforementioned MLC modeling parameters into the dose calculation algorithm since the version 7.4 onward. The Eclipse TPS (version 8.5 or later) also incorporated the TG effect into the leaf motion calculation[17] as well as all 3-dimensional (3D) dose calculations (pencil beam convolution and analytical anisotropic [AAA] algorithms) for static, IMRT, and RapidArc fields. However, unlike Pinnacle, some MLC parameters in Eclipse (*e.g.*, TG offset width and thickness) are neither user-definable nor configurable. To compute the second source fluence from the MLC, for instance, the AAA algorithm of the Eclipse models the MLC as a single plane. Further, the off-axis variation in the second source spectrum is not considered.[17] Thus, one needs to verify whether the TPS properly accounts for the TG effect and its dependence on depth and off-axis dose profiles.

The dose dip at the interleaf position of TG for the Varian Millennium 120 MLC (Varian Oncology Systems, Palo Alto, CA) has been studied by many researchers. They used Monte Carlo (MC) simulations and film measurements.[18-23] For MLC modeling in the TPS, 1 group[24] developed a generalized model of MLC that accounted for direct MLC transmission, MLC scatter, beam hardening, and leaf-end transmission. They showed that MLC scatter could reach up to approximately 10% of the total dose and an inadequate model of MLC transmission in TPS (constant-value model) can result in the dose discrepancies between the IMRT plan and measurements. They mentioned a need of future study for the integration of TG effect into the dose calculation algorithm. However, these studies did not provide sufficient information to determine the TG effect on in-water depth and off-axis distance.

In this study, we evaluated accuracy of the TG dose calculation for Eclipse and Pinnacle as varying depths and off-axis distances in solid water. The TPS calculations were compared with MC simulations and radiochromic film (RCF) measurements. The TG effect was quantified as the maximum depth and full width at half maximum (FWHM) of the dose dip at the interleaf position and the total amount of underdosage within the dip for various off-axis distances and depths in solid water.

Methods and Materials

General information

We investigated Varian Millennium 120 MLC, which has 3 different types of leaf shape: "'isocenter," "target," and "full."[19] The leaf widths are 5 mm for the central 80 leaves and 10 mm for the outer 40 leaves at the source-to-surface distance (SSD) of 100 cm. The "isocenter-" and "target"-type leaves cover the central 20 cm of the field and the "full"-type leaves form the outer 40 leaves. To calculate and measure the TG effect only, both the jaws of the collimator were fixed to create an opening of 12 × 36wsm, and 5 different MLC fields (Fig. 1) were generated:

(1) A 12 cm × 36-cm symmetric open field
(2) Two fields asymmetric in the y-direction and abutting at the central axis (*i.e.*, at y = 0 cm); 12 cm × 18 cm (y_1 = 0 cm, y_2 = 18 cm) + 12 cm × 18 cm (y_1 = 18 cm, y_2 = 0 cm)
(3) Two fields asymmetric in y-direction and abutting at y = 5 cm; 12 cm × 23 cm (y_1 = 5 cm, y_2 = 18 cm) + 12 cm × 13 cm (y_1 = 18 cm, y_2 = − 5 cm)
(4) Two fields asymmetric in y-direction and abutting at y = 10 cm; 12 cm × 28 cm (y_1 = 10 cm, y_2 = 18 cm) + 12 cm × 8 cm (y_1 = 18 cm, y_2=-10 cm)
(5) Two fields asymmetric in y-direction and abutting at y = 13 cm; 12 cm × 31 cm (y_1 = 13 cm, y_2 = 18 cm) + 12 cm × 5 cm (y_1 = 18 cm, y_2 = − 13 cm)

The open field (1) was used as the reference and other fields were designed to consider all of possible combinations of leaf types:

(2) "isocenter" + "isocenter"
(3) "target" + "target"

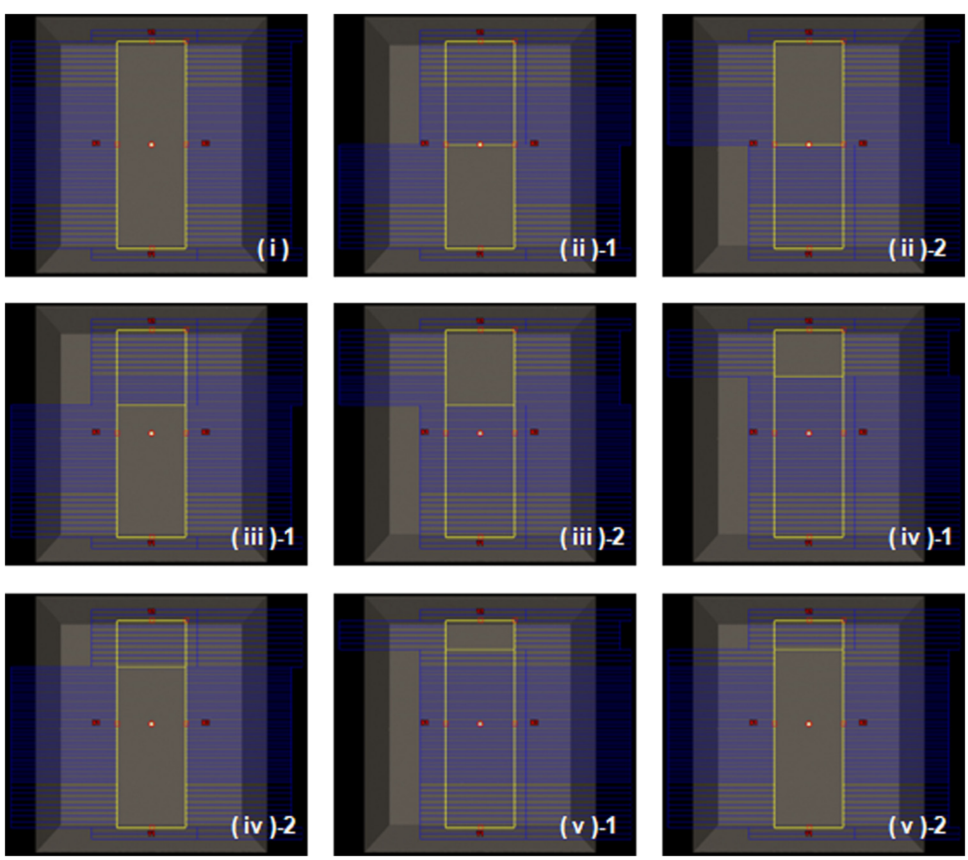

Fig. 1. Configuration of MLC field geometries in this study (captured from the Eclipse TPS). (Color version of figure is available online.)