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Dosimetric equivalent machines and MLC configurations with Enhanced Leaf Model (ELM)

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ABSTRACT

Purpose:
Enhanced Leaf Model (ELM) introduced in Varian Eclipse v18 has demonstrated improved commissioning efficiency and consistency and shown equivalent or superior dose calculation accuracy such as for HyperArc. This study investigated the feasibility of using ELM to configure MLC for dosimetric equivalent machines.

Methods:
Four Varian TrueBeam with Millennium MLCs were beam-matched during commissioning. A set of optimal DLG_v16 and Transmission was fine-tuned with dynamic chair pattern and used for all four linacs in Eclipse v16. In Eclipse v18, machine-specific DLG_ELM and Transmission were derived from sweeping gap measurements for each linacs and a set of optimal DLG_ELM and Transmission was also determined and used for all four linacs for dosimetric equivalent machine purpose. Gamma analysis was performed for dynamic chair pattern calculated in Eclipse and measured on each linac. PSQA were delivered and analyzed with 2%-2mm or 2%-3mm for various disease sites.

Results:
With the optimal DLG_v16 and Transmission set used for all four linacs, dynamic chair pattern gamma passing rates (2mm-2%, 10% threshold) exceeded 99.1%, 96.9%, 98.1%, 99.8%, and 98.7% for 6X, 6F, 10X, 10F, and 15X respectively. With optimal DLG_ELM and Transmission, the corresponding gamma passing rates at 2mm-2% were > 95.8%, 92.3%, 98.6%, 98.9%, and 89.9% respectively. When evaluated using 2mm-3% criteria, gamma passing rates improved to > 98.5%, 95.7%, 99.5%, 99.8%, and 99.8% for the same energies. Patient-specific quality assurance (PSQA) was performed for five representative clinical disease sites. Gamma passing rates exceeded 98.0% for both the conventional model DLG_v16 and the enhanced leaf model DLG_ELM using 2mm-3% criteria for conventional VMAT plans and 2mm-2% criteria for SBRT cases.

Conclusion:
Enhanced Leaf Model accounts for MLC rounded leaf-end and real leaf thickness for dose calculations. While it was designed to derive DLG_ELM and Transmission for each specific linac, it is possible to determine an optimal set for all machines and take advantage the convenience of dosimetric equivalent machines.

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INTRODUCTION

Accurate modeling of multileaf collimator (MLC) characteristics is essential for advanced radiotherapy techniques, including intensity-modulated radiation therapy (IMRT), volumetric-modulated arc therapy (VMAT), stereotactic radiosurgery (SRS), stereotactic body radiation therapy (SBRT), and HyperArc. Accurate dose calculation depends on realistic modeling of MLC geometry and transmission, particularly for highly modulated treatments with small fields and steep dose gradients.

Previous versions of the Varian Eclipse treatment planning system modeled MLC leaf-end effects using the Dosimetric Leaf Gap (DLG) and average MLC transmission factor. Because DLG is an empirical parameter, its optimal value depends on the beam model, measurement technique, detector characteristics, and treatment complexity, often requiring iterative commissioning. Eclipse version 18 introduced the Enhanced Leaf Model (ELM), which incorporates rounded leaf ends and finite leaf thickness (Figure 1) and derives machine-specific parameters from sweeping gap measurements.

Previous studies have demonstrated equivalent or improved dose calculation accuracy using ELM for IMRT, VMAT, SBRT, and HyperArc. However, many radiation oncology centers operate multiple beam-matched linear accelerators to enable patient treatment on any machine without replanning.

This study evaluated whether a common ELM parameter set can be applied across beam-matched Varian TrueBeam linear accelerators equipped with Millennium MLCs. Dosimetric performance was compared with the conventional DLG model to determine whether a common ELM parameter set can maintain dosimetric equivalence while simplifying commissioning.

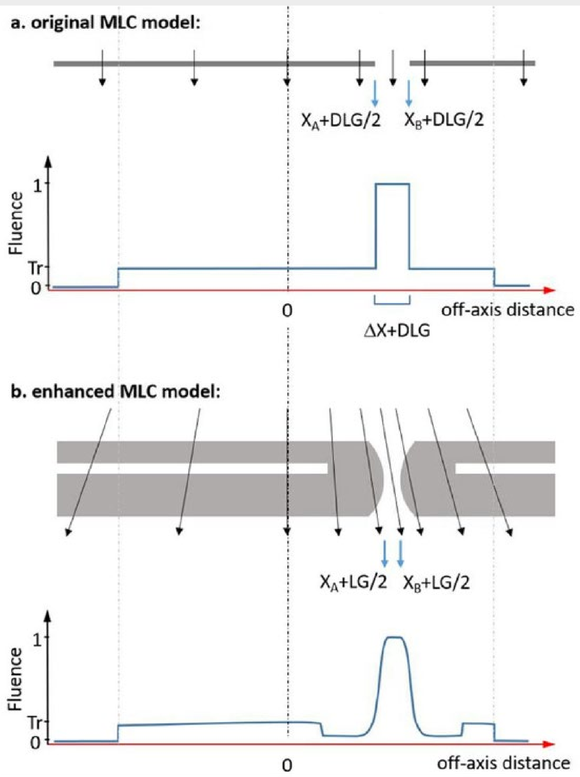

Figure 1. Original (a) and Enhanced multileaf collimator (MLC) by Ann Van Esch et al, DOI: 10.1002/mp.16019

METHODS AND MATERIALS

Four Varian TrueBeam linear accelerators equipped with Millennium 120 MLCs were beam-matched during commissioning. In Eclipse v16, a common set of optimized dosimetric leaf gap (DLG_v16) and MLC transmission values was established using the dynamic chair pattern and applied to all four linacs. After upgrading to Eclipse v18, machine-specific Enhanced Leaf Model (DLG_ELM) and transmission values were derived for each linac from sweeping gap measurements. A single optimized DLG_ELM and transmission parameter set was also determined and applied to all four beam-matched linacs to evaluate its feasibility for dosimetrically equivalent machines.

DLGs were assessed by comparing Eclipse-calculated and measured dynamic chair pattern (Figure 2) dose distributions for 6X, 6FFF, 10X, 10FFF, and 15X beams. Clinical performance was further evaluated using patient-specific quality assurance (PSQA) plans representing five disease sites including HN, Prostate, Pelvis, Breast and Lung. Gamma analysis was performed using a 10% dose threshold with criteria of 2mm-2% for SBRT plans and 2mm-3% for VMAT plans. A gamma passing rate of at least 95% was considered clinically acceptable.

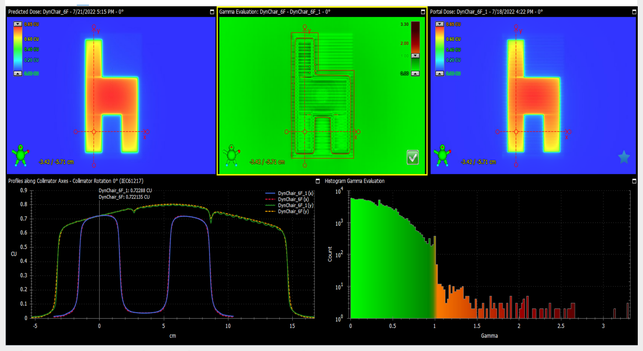

Figure 2. Dynamic chair pattern used to tune MLC parameters

RESULTS

The DLG_ELM and transmission values derived from sweeping gap measurements for all four Varian TrueBeam linacs are summarized in Table I. Machine-specific parameters are presented for each linac, followed by the average values across all four systems. The final row lists the optimized common parameter set selected for dosimetrically equivalent beam modeling and implemented on all four linacs in Eclipse v18.

		TB1	TB2	TB3	TB4	ELM_Avg	ELM_Final
6X	Trans	0.013574	0.014591	0.014014	0.014267	0.014112	0.014112
	DLG	-0.007703	-0.018290	-0.027873	-0.038975	-0.023210	-0.023210
6F	Trans	0.011547	0.012396	0.011890	0.012254	0.012022	0.011547
	DLG	-0.015938	-0.024871	-0.031629	-0.042338	-0.028694	-0.042338
10X	Trans	0.015660	0.016667	0.016000	0.016382	0.016177	0.016177
	DLG	-0.000073	-0.009450	-0.018411	-0.028928	-0.014216	-0.014216
10F	Trans	0.013806	0.014917	0.014336	0.014684	0.014436	0.014436
	DLG	-0.005096	-0.011750	-0.021236	-0.031129	-0.017303	-0.017303
15X	Trans	0.015124	0.016082	0.015414	0.015794	0.015604	0.015604
	DLG	-0.000100	-0.005971	-0.015623	-0.026466	-0.012040	-0.012040

Table I. DLG_ELM measured from sweeping gap test, the ELM_Final set was determined from dynamic chair patten.

RESULTS

Gamma analysis results for the dynamic chair test pattern on all four Varian TrueBeam linacs are summarized in Table II for both the conventional DLG_v16 model and the Enhanced Leaf Model DLG_ELM. Gamma evaluations were performed using 2mm-2% and 2mm-3% criteria for all photon energies, including 6X, 6FFF, 10X, 10FFF, and 15X.

Gamma		DLG_v16		DLG_ELM	
	TB1	2mm-2%	2mm-3%	2mm-2%	2mm-3%
TB1	6X	99.3	99.7	98	99.9
	6F	99.8	99.9	95.9	99.9
	10X	98.1	99.5	99.1	100
	10F	99.9	99.9	99.9	99.9
	15X	98.7	99.5	89.9	99.8
TB2	6X	99.1	99.7	96.3	99.1
	6F	98.6	99.8	93.3	97.2
	10X	99.2	99.8	98.9	100
	10F	99.8	99.9	99.7	99.8
	15X	99.5	99.9	98.9	99.9
TB3	6X	99.4	99.8	96.9	99.5
	6F	98.4	99.8	93.7	97.5
	10X	99.5	99.9	99.1	99.9
	10F	99.8	99.9	99.5	99.9
	15X	99.6	100	93.5	99.9
TB4	6X	99.1	99.8	95.8	98.5
	6F	96.9	99.8	92.3	95.7
	10X	98.9	99.7	98.6	99.5
	10F	99.8	99.9	99.2	99.9
	15X	99.7	99.9	93.1	99.8

Table 2. Gamma analysis results for dynamic chair pattern

Gamma analysis results for PSQA on all four Varian TrueBeam linacs are summarized in Table III for both the conventional model DLG_v16 and the Enhanced Leaf Model DLG_ELM. Gamma evaluations were performed using 2mm-2% and 2mm-3% criteria for photon energies including 6X, 6FFF, 10X, and 10FFF.

	2mm-3%	v16	v18_TB1	v18_TB2	v18_TB3	v18_TB4
HeadNeck	6X	>99.8	>99.9	>99.8	>99.8	>99.8
Prostate	6X	>95.7	>100	>100	>99.8	>99.5
GYN	10X	>100	>99.8	>99.9	>100	>99.9
Pelvis	10X	>98.7	>99.9	>99.9	>99.8	>99.7
	2mm-2%	v16	v18_TB1	v18_TB2	v18_TB3	v18_TB4
Breast APBI	6FFF	>99.3	>99.5	>99.7	>99.1	>99.3
Breast APBI	6FFF	>98.6	>98.7	>98.9	>97.8	>98.6
Lung SBRT	10FFF	>99.6	>99.9	>99.9	>99.6	>99.7
Lung SBRT	10FFF	>99.7	>98.4	>100	>99.0	>99.4

Table 3. Gamma analysis results for PSQA

CONCLUSIONS

Enhanced Leaf Model (ELM) is an advanced dose calculation algorithm that more accurately models the physical characteristics of multileaf collimators (MLCs), including the rounded leaf ends and finite leaf thickness. Compared with the conventional DLG approach, ELM provides improved representation of MLC transmission and leaf-end effects in Eclipse dose calculations. Although ELM is intended to determine machine-specific DLG_ELM and transmission values for each individual linac, it may be possible to establish a single optimized parameter set that can be shared across multiple beam-matched linacs. Such an approach would preserve the clinical advantages and operational simplicity of dosimetrically equivalent machines while maintaining accurate dose calculation.

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