Evaluation of MLC Thickness and Composite Effects on Collimation Parameters using EGSnrc and IAEA Phase Space Data

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ABSTRACT

Background: Recently, multileaf collimators (MLC) have become an important part of any LINAC collimation system because they reduce the treatment planning time and improve the conformity. Important factors that affect MLCs collimation performance are leaves material composition and their thickness.

Objective: In this study, we investigate main dosimetric parameters of a typical MLC including dose in the buildup point, physical penumbra as well as average and end leaf leakages. Effects of the leaves geometry and density on these parameters are evaluated.

Materials and Methods: In this analytical study, calculations were performed by using phase space data for Varian ix just above MLC and BEAMnrc/DOSXYZnrc for SSD=100cm and in a water phantom.

Results: Based on the results, a new MLC with improved dosimetric parameters is proposed. The physical penumbra for proposed MLC is 4.7mm was compared to 5.16 mm for Millennium 120 leaf. Average leakage in our design is reduced to 1.16% compared to 1.73% for Millennium 120 leaf, the end leaf leakage suggested design also reduced to 4.86% compared to 7.26% for Millennium 120 leaf.

Conclusion: The results show that the proposed MLC could improve the dosimetric parameters and conformity of treatment planning.

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Keywords

Phantoms, Imaging; Radiometry; Particle Accelerators

Introduction

MLCs have become important tools in LINAC collimation systems. The main concern in the use of MLCs for stationary fields is the conformity between planed boundary as well as reduction in setup and treatment time [1].

MLCs are considered as an essential tool for intensity modulated radiation therapy (IMRT) which is becoming the standard of care in radiation oncology facilities. All linear accelerator makers have provided some kinds of MLC for conformal and IMRT treatments. The MLC characteristics for each manufacturer have been studied by many researchers [2] and comparative physical characteristics are reported in AAPM report [3].

Dosimetric parameters, affected when using MLC in IMRT, have been studied extensively [4-7]. Using ionization chamber, Burmeister and

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Sharma evaluated leakage characteristics of two Varian MLCs during IMRT delivery [8]. His result showed that Mark –I leakage in the leaf motion was very similar to Millennium 120-leaf leakage in either direction and Mark-I leakage was higher than perpendicular to the leaf motion direction. Appenzoler et. al. [9] compared the physical penumbra and transmission of the Siemens 160 MLC and the Varian 120 MLC for 6 and 10MV photon beams; measurement were performed using a new sun nuclear EDG^{TM} diode detector and Kodak EDR2 film and 0.6cc farmer type ion chamber.

In IMRT, each beam breaks into small beamlets and determines the intensity of each beamlet width as about 1cm×1cm; because of small size of the beamlet determination of dosimetric parameters such as physical penumbra and average leakage and end leaf leakage are important. Although small changes in the penumbra and leakage will have a great impact on the results [9].

In this study, we calculate dosimetric parameters including the buildup dose, physical penumbra as well as average and end leaf leakages. Effects of the leaves geometry and density on these parameters are evaluated. Calculations are performed by using phase space data for Varian IX just above MLC and BEAMnrc/DOSXYZnrc for SSD=100cm and in a water phantom. Based on the results, a new MLC with improved dosimetric parameters is proposed.

Material and Methods

In this analytical study, EGSnrc Monte Carlo code is used for dosimetric characteristics evaluations in this study. EGSnrc is a Monte Carlo simulation package for electrons and photons transport with energies between 40 KeV to several TeV which has been extensively employed for electron and photon dosimetry [10-15]. BEAMnrc and DOSXYZnrc, two of the principal modules in EGSnrc, are utilized for simulating the sources (LLINAC, brachy sources, etc.) and calculating dose distribution in rectilinear or CT phantoms, respectively [11].

Millennium MLC Dosimetric Parameters

Physical Penumbra

For an incident beam on a phantom, the absorbed dose varies with depth. There is an initial region where absorbed dose increases with depth (buildup region) after which absorbed dose decrease with depth [1].

At each depth of a phantom, the absorbed dose is greatest on the beam central axis and decreases toward the beam edge as a function of lateral distance from the beam axis. The physical penumbra width is defined as the lateral distance between two isodose curves at a specified depth (lateral distance between 80% and 20% isodose line) [16]. Utilizing Millennium 120-leaf MLC specifications (Table 1) and by using EGSnrc, Millennium 120-leaf MLC analysis is carried in 3 steps.

Table 1: Physical characteristic of Millennium 120 leaf MLC [17].

Number of the leave	60 pair
Number of the central leave	20 pair
Thickness of the central leave	0.5 cm
Thickness of the lateral leave	1 cm
Maximum field size of MLC	40×40 cm^2
Leaf height	6 cm
Radius of the end leaf	8 cm
Leaf Length	15 cm
Leaf density	17.5 gr/cm^3

- In step one, BEAMnrc is used to generate a new phase space data based on the variations made in Millennium MLC. For this purpose, IAEA phase space data for Varian IX LINAC just above MLC in z=46cm together with modified MLC is modelled in BEAMnrc to produce a new phase space data at z=52cm [18].
- In step two, using DOSXYZnrc and the new phase space generated in step one, dose distribution in a water phantom of 40×40×20

cm^3 with voxel size of 4×4×2 mm^3 is evaluated.

- In step three, using DOSXYZnrc output (3dose file) and STATDOSE (EGSnrc data extraction utility) together with XMgrace (plotting utility) depth doses curve and dose profiles are plotted.

Average Leakage and End Leaf Leakage

Average leakage and end leaf leakage are determined in a depth of 5cm of a 60×60×20 cm^3 water phantom having voxel size of 6×6×2 mm^3. Beam profile obtained for closed leave at 5cm distance from central axis and entirely opened MLC at 5cm depth of phantom [19].

Based on the beam profile, opened and closed states of MLC and definition, the end leaf and average leakages and their corresponding uncertainties are:

$$L_{ave} = (\sum_{0}^{99} Dci \,/ \sum_{0}^{99} Doi) \times 100 \qquad (1)$$

$$\Delta(L_{ave}) = (\sum_{0}^{99} \frac{\Delta Dci}{Dci} + \sum_{0}^{99} \frac{\Delta Doi}{Doi}) \times L_{ave}$$

$$L_E = (Dc \,/ \sum_{0}^{99} Doi) \times 10000$$

$$\Delta(L_E) = (\frac{\Delta Dc}{DC} + \sum_{0}^{99} \frac{\Delta Doi}{Doi}) \times LE$$

Where L_{ave} and L_E are average and end leaf leakages, respectively. *Dci* and *Doi* are doses in a voxel in x direction (y=0, z=5) for closed beam and open beam, respectively. *Dci* is the dose corresponding to the end leaf for a closed beam(x=10.5, y=0, z=5).

EGSnrc Validation

For validation of our MLC modelling, data obtained in part A are compared with the measured values of PDD for Varian LINACs based on IAEA TRS 398 protocol [20].

Dosimetric Parameters in Different Geometries

The leaf thickness is a feature of the MLC. In this study, the effects of leaf thickness on dosimetric parameters are evaluated. (Table 2).

For calculation of physical penumbra, average leakage, end leaf leakage and buildup dose for MLCs with different geometries, all the aforementioned steps are carried out. In BEAMnrc code, thickness of the leaves and their setup according to Table 2 are modelled.

Dosimetric Parameters for Different MLCs Leave Densities

Effect of the leaves density as an important factor on the dosimetric parameters is investigated. In Millennium MLC, the leave is made of tungsten alloy with 17.5gr/cm^3 density. Table 3 shows tungsten alloy with various densities [21].

EGSgui code is used to prepare necessary 521ICRU library for tungsten alloys [10, 11]. For evaluating the physical penumbra, average and end leaf leakages as well as buildup dose for different MLC geometries for each density are calculated. The leaves geometry is modelled in BEAMnrc to produce a new phase space data for each configuration.

Dosimetric Parameters for the Suggested MLC

Based on our results, the physical characteristics presented in Table 4 are realized to improve MLC dosimetric parameters including, end leaf leakage, average leakage and physical penumbra.

Results

Validation

Values of depth dose data Varian IX derived from Millennium 120 leaf simulation com-

Table 2: Different thickness of the leaves and their number.

Thickness of lateral leaves(cm)	Number of lateral leaves	Thickness of central leaves(cm)	Number of central leaves
1	40	0.4	100
1	40	0.25	160

Table 3: Characteristic of various tungsten alloys

Alloy	Tungsten %	Iron %	Nickel %	Copper %	Density (gr/cm^3)
1	93	2.0	5.0	0	17.5
2	95	1.6	3.4	0	18.0
3	97	0.8	1.6	0.6	18.5

Table 4: Physical characteristic for the suggested MLC.

Number of central leave	100
Central leave thickness	0.4 cm
Number of lateral leave	20
Lateral leave thickness	2 cm
Leaves density	18.5 gr/cm^3

pared with the measured values of dosimetric parameters for Varian LINACs based on IAEA TRS 398 protocol are presented in Table 5.

The Varian IX modelling performed with EGSnrc code has produced dosimetric parameters presented in Table 5, and are in a good agreement with IAEA TRS 398 protocols.

Depth Dose Data and Physical Penumbra

Table 6 presents the physical characteristics of MLCs, buildup dose and physical penumbra width for SSD=100cm.

End Leaf Leakage and Average Leakage

Based on the beam profile for open beam and closed beam and dose distribution as well as definition for leakages, the end and average leakages are calculated and presented in Table 7.

Dosimetric pParameters of the Suggested MLC

Based on our dosimetric calculations, the dosimetric parameters as well as the physical characteristics of the new MLC are presented in Tables 8 and 9.

Discussion

As illustrated in Table 5, values of depth dose data for Varian IX derived from Millennium 120 leaf simulation are in close agreement with the measured values of dosimetric parameters for Varian LINACs based on IAEA TRS 398 protocol. Considering depth dose data for MLC with different geometries and densities, it could be concluded that the depth of the buildup region is independent of the geometry (leaves thickness and density). By comparing the physical penumbra width for various geometry, it could be concluded that with decreasing central leaf thickness and increasing the leaves density, physical penumbra width decreases. MLC with less leaf width improves dose conformity to the target volume. The reduced physical penumbra width from increasing the leaves density is more effective than decreasing the central leave thickness.

Conclusion

In this study, end leaf leakage and average leakage as two important dosimetric parameters are calculated. By comparing the end

Table 5: Values of depth dose data Varian IX derived from Millennium 120 leaf MLC and values of dosimetric parameters for Varian LINACs based on IAEA TRS 398 protocol, SSD=100, field size 10×10

LINAC	$R_{100\ mm}$	$R_{50\ mm}$	$D_{100\ \%}$	$D_{200\ \%}$
Varian IX IAEA TRS 398 protocol	17.00	148.85	66.39	35.65
EGSnrc Varian IX model results	16.04	153.88	67.29	38.72

Table 6: Physical characteristics the MLCs and their dosimetric parameters.

Physical Penumbra (mm)	Leaves density (gr/cm^3)	Number of the central leave	Central leave thickness (mm)	Number of leaves
5.16	17.5	80	5	120
5.15	17.5	100	4	140
5.11	17.5	160	2.5	200
4.95	18	80	5	120
4.4	18.5	80	5	120

Table 7: Physical characteristic of the MLCs and average and end leaf leakages.

End leaf leakage (%)	Average leakage (%)	Leaves density (gr/cm^3)	Number of the central leave	Central leave thickness (mm)	Number of leaves
7.26	1.73	17.5	80	5.0	120
7.19	1.77	17.5	100	4.0	140
8.5	1.79	17.5	160	2.5	200
6.3	1.34	18	80	5.0	120
5.2	1.18	18.5	80	5.0	120

Table 8: Physical characteristic suggested MLC.

Leaves density (gr/cm^3)	Lateral leave thickness (mm)	Number of the lateral leave (pairs)	Central leaves Thickness (mm)	Number of the Leave (pairs)
18.5	20	10	4	60

Table 9: Dosimetric parameters suggested MLC.

Average end leakage (%)	End leaf leakage (%)	Physical penumbra width (mm)	Build up Dose (Gy)	build up depth (cm)
1.16	4.86%	4.7	1.12e-16	1.3

leaf leakage and average leakage in different conditions, it could be concluded that with decreasing central leaf thickness, end leaf leakage and average leakage increase. Meanwhile, with increasing leaves density, end leaf and average leakages decrease. With increasing leaves density, penumbra width, end leaf leakage and average leakage parameters are improved. Therefore, the density of the leave is an effective factor to improve dosimetric parameters. Decreasing thickness, the central leave improves the penumbra width parameter but increases the leakage from the leave.

In order to improve the MLC dosimetric parameters, MLC with a new design is suggested. In the new design, leave density is 18.5 gr/cm^3, and thickness of the central and lateral leaves are respectively 4mm and 2cm.

Central leaves have more effect on beam shaping and physical penumbra width than the lateral leaves. For improving beam shaping and physical penumbra, central leaves thickness is suggested to be decreased. Therefore, for compensating the increased leakage from the leaves, lateral leaves thickness is suggested to be decreased.

The physical penumbra suggested in new design is 4.7mm, while it is 5.16mm for Millennium 120 leaf. Average leakage suggested design is 1.16%, while it is 1.73% for Millennium 120 leaf, end leaf leakage suggested design 4.86% and 7.26% for Millennium 120 leaf. The results show that the proposed MLC has the dosimetric advantage and improved dosimetric parameters compared to Millennium 120 leaves.

Conflict of Interest

None

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