Original Article

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Evaluation of Dosimetric Characteristics of a Double-focused Dynamic Micro-Multileaf Collimator (DMLC)

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Double-focused micro-Multileaf Collimator (μMLC) is able to create radiation fields having sharper dose gradients at the field edges than common MLC. Therefore, μMLC has been used for the stereotactic radio-surgery (SRS) and Stereotactic Radiotherapy (SRT). We evaluated the dosimetric characteristics of a double-focused Dynamic-μMLC (DMLC) attached to the Elekta Synergy linear accelerator. For this study, the dosimetric parameters including, Percent Depth Dose (PDD), Leaf leakage and penumbra, have been measured by using of the radiochromic films (GafChromic EBT2), EDGE diode detector and three-dimensional water phantom. All datas were measured on 6 MV x-ray. As a result, The DMLC shows transmission below to 1% and because of double-focused construction of the DMLC, the penumbras of fields with DMLC are independent from the field sizes. In this paper, the resulting dosimetric evaluations proved the applicability of the DMLC attached to the Elekta Synergy linear accelerator.

Key Words: Dynamic micro-Multileaf Collimator, PDD, Leaf transmission, Penumbra

Introduction

A Multileaf collimator (MLC) has been clinically used for both conventional and irregular radiation fields shaping. Due to individually movable leaves fields of high complexity can be generated. The MLC was integrated in almost every modern linac. The commonly used leaf width of MLC is 1～1.25 cm. Stereotactic Radio-Surgery (SRS) and Stereotactic Radiotherapy (SRT) are concerned to treat small lesions with irregular field shape. The smaller MLC dimensions, the more useful for treatment with small radiation fields. A variation of this device is the so-called micro-MLC (μMLC). Nowadays, the leaf width of the μMLC is less than 5 mm.[1,2] The μMLC designs can be classified into two groups, single-focused and double focused. The leaf ends as well as the leaf sides match the beam divergence, making the configuration double-focused. The advantage of such a precise collimation is the independence of the penumbra from the location of the field.[3] This focusing with respect to dose distributions have been presented by Meeks et al.[4] Therefore, the double-focused μMLC is a very useful collimation system for SRS and SRT.[5] In this study, we evaluated the dosimetric parameters including, Percentage Depth Dose (PDD), Interleaf leakage, Intra-leaf transmission, leaf-end transmission and penumbra of a double-focused Dynamic-μMLC (DMLC, 3D Line, USA Inc.). It was attached to the Elekta Synergy Linear accelerator. All data were measured on 6 MV x-ray.

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Materials and Methods

1. DMLC system

The Dynamic Micro-multileaf collimator (DMLC) provided by 3D Line is part of the DynART (Dynamic Arc Radiation Therapy) system. The DMLC is double-focusing and has 24 pairs of tungsten leaves that each project 2.9 mm width at the isocenter. Therefore, the maximum field size is 68.3×69.7 mm^2. The DMLC was attached to the Elekta Synergy linear accelerator (Fig. 1). The DMLC is coupled to the linac (linear accelerator) at 624 mm from the source (Fig. 2(a)).[6)] Leaves describe a convex path, so the photon beam will be focused both in the motion direction and in the transverse direction. In order to reduce transmission through the leaves, DMLC are slightly divergent that leads rather to the so-called triangular tongue and groove effect (Fig. 2(b)).[6,7)] When the gantry was positioned at 180^o, the DMLC can be manually attached to the accessory mount of the linac by the help of a specially designed trolley. The electrical connection between the DMLC and gantry of the linac is based on a single cable, which can be connected very easily.

The physical characteristics of this DMLC and BrainLAB m3 are described in Table 1.

2. Percent depth dose (PDD)

The measurements were obtained using a EDGE Detector™ (Sun Nuclear Corporation, Melbourne, FL) and a Blue Phantom² three-dimensional scanning system (IBA Dosimetry GmbH). The central axis PDDs were measured in water for square field sizes, 3.6×3.6 cm^2 and 6.0×6.0 cm^2 and Source to Surface Distance (SSD) at 100 cm. The measured datas were normalized to the maximum depth dose of 6 MV x-ray.

3. Leaf leakage

We measured interleaf leakage, intra-leaf and leaf-end transmission.[3)] To measure interleaf leakage and intra-leaf transmission, all leaves of the DMLC were closed. Due to the

Fig. 1. Dynamic micro-multileaf collimator (DMLC) attached to the Elekta Synergy linear accelerator. The electrical connection between the DMLC and the gantry is established by only on cable.

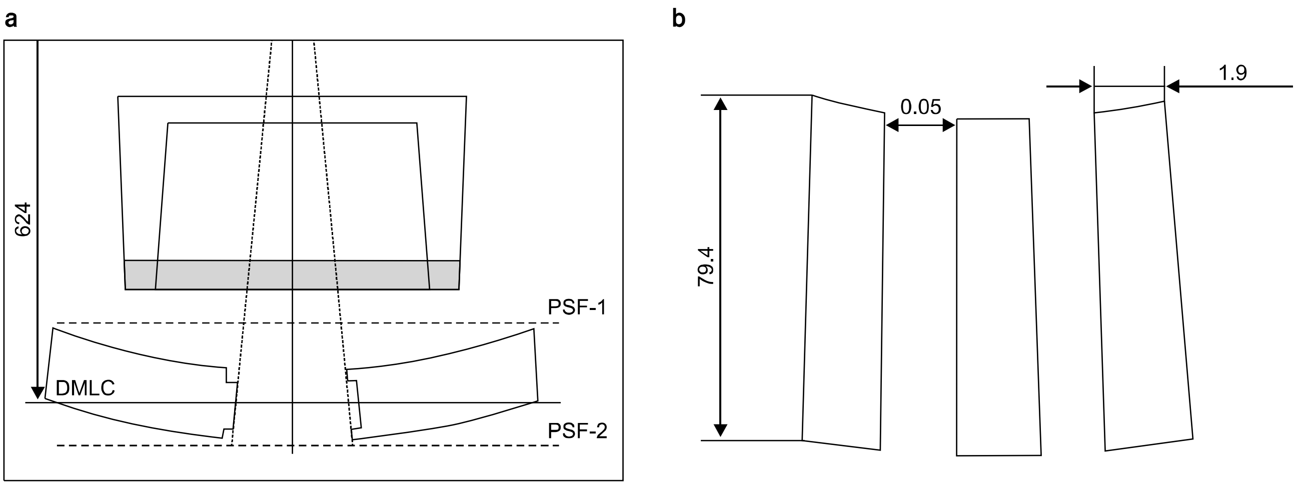

Fig. 2. (a) Scheme of the transverse view of the DMLC. (b) Detail of the leaves of the DMLC. All distance are in mm.

Table 1. Physical characteristics of the 3D Line DMLC and BrainLAB m3.

	3D Line DMLC	BrainLAB m3
Number of leaves	48 (24 pairs)	52 (26 pairs)
Leaf Material	Tungsten (93%)	Coated tungsten
Leaf Height	80 mm	-
Real leaf width	1.9 mm	-
Leaf width at isocenter	2.9 mm	14 pairs at 3 cm 6 pairs at 4.5 cm 6 pairs at 5.5 cm
Maximum field size at isocenter	68.3×69.7 mm^2	98×98 mm^2
Weight (approx.)	30 kg	30 kg
Design	Double-Focused	-
Leaf speed	1.0 cm/s	1.5 cm/s

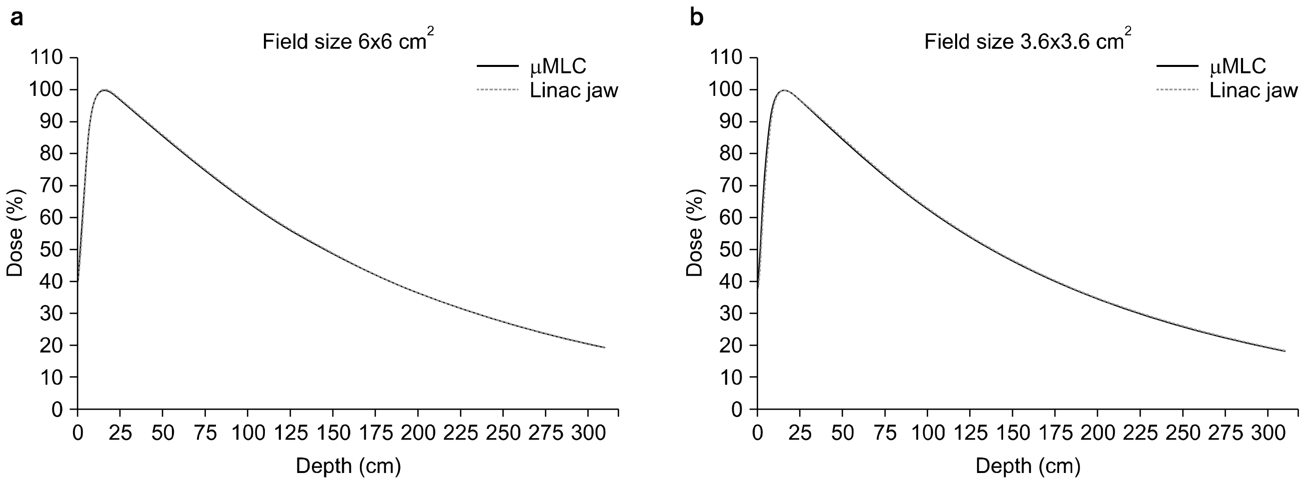

Fig. 3. Percent depth dose of (a) field size 6×6 cm^2, (b) 3.6×3.6 cm^2 for 6 MV.

small amount of collimator transmission, the linac jaws were opened as 7×7 cm^2. The radiochromic films (GafChromic EBT2) were used for the measurement. The films were positioned perpendicularly to the beam central axis in the solid water phantom at a depth 5 cm and SAD 100 cm. The films were exposed to 6 MV x-ray for 6,000 monitor units. Also, to confirm the leaf-abutting setup, the five sequential field shapes were used. The shape of each field was closed and the abutment location was translated by 1.5 cm steps over the course of the sequence.[8] Each exposure was for 1,200 MU. We got the vertical profiles for first film and cross-line profiles for second film. The films were scanned with a Epson Perpection V1000 scanner. The software we used to analyze the scanned 48-bit RGB tiff images of the EBT2 films was based on MATLAB R2015a.

4. Penumbras and field sizes

The measurements of Penumbras were made at the depth of 1.5 and 5 cm, SSD 100 cm. Because the leaves are designed to match the beam divergence, the penumbra should be independent from the field sizes. To confirm this, penumbra datas were obtained. We measured beam profiles of 3.6×3.6 cm^2, 4.8×4.8 cm^2, 6.0×6.0 cm^2 field sizes.

Results and Discussions

1. Percent depth dose (PDD)

As shown in Fig. 3, measured PDD datas with or without the DMLC were similar. The DMLC does not significantly affect the depth-dose characteristics of the linear accelerator.

2. Leaf leakage

Fig. 4 shows the leaf leakage of the DMLC. The maximum interleaf leakage between the leaf sides was determined as 0.94%, where the maximum transmission through the leaves 0.79%. The transmission slightly increased more than 4.7 mm width μMLC.[2)] We considered the scatter of interleaf uptake as short as the leaf width. The maximum transmission between leaf-ends (i.e., where the leaves from opposite sites met at the central axis) was determined to be 1.37%. The transmission between leaf-ends is dependent on leaf alignment. Table 2[9)] shows the comparison of transmission and leakage between DMLC and commercial μMLC (m3; BrainLAB, Heimstetten, Germany). Currents measurements are in agreement with the AAPM TG 50 recommendation which recommends 2% as a maximum value for transmission. As shown in Fig. 5, we could check the leaf-end leakage peaks at −3.0 cm, −1.5 cm, 0 cm, 1.5 cm and 3.0 cm. These peaks shown the stability of the abutted leaf setup.

3. Penumbras and field sizes

As shown in Table 3, The 80～20% beam penumbras average over all field size were 2.66 mm along the leaf end. These values are in good agreement with measurements of BrainLAB m3, which are 2.31 mm.[9)] The measured width of penumbras were not significantly different compared to the linac jaw and independent from the field size.

Table 2. Transmission & Leakage of 3D Line DMLC and BrainLAB m3.

	Transmission (%)	Leakage (%)
m3-MLC	0.93	1.18
3D Line DMLC (This work)	0.79	0.94

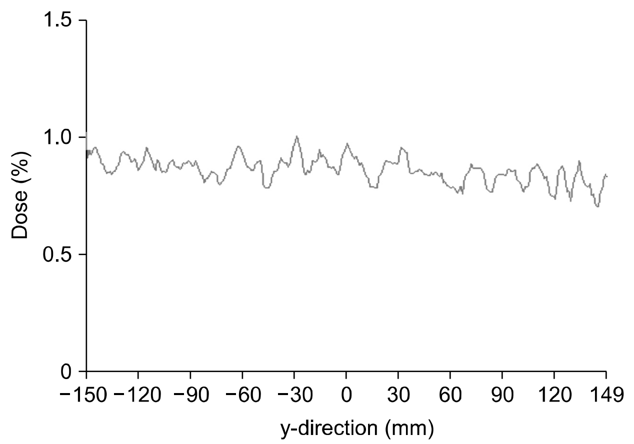

Fig. 4. In-plane profile about interleaf leakage and intra-leaf transmission. The field closed at isocenter.

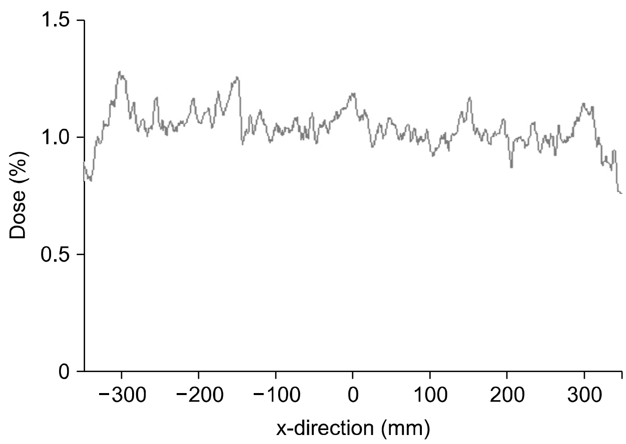

Fig. 5. Cross-plane profile about abutted leaf setup field. The position of 5 peaks shown the abutted leaf position.

Table 3. Penumbras (mm) for 3.6×3.6, 4.8×4.8, 6.0×6.0 cm^2 field sizes defined using the DMLC and Linac jaws. The datas were measured at SSD 100 cm at depths of 1.5 cm and 5 cm in water using a EDGE Detector.

Field Size	3.6×3.6 cm^2		4.8×4.8 cm^2		6.0×6.0 cm^2	
	DMLC	Linac jaws	DMLC	Linac jaws	DMLC	Linac jaws
80～20% d=1.5 cm	2.6	2.8	2.7	2.9	2.7	2.9
80～20% d=5.0 cm	3.0	3.0	3.1	3.2	3.1	3.1

Conclusions

We evaluated the dosimetric characteristics of DMLC attached to the Elekta Synergy linear accelerator. PDDs measured by the DMLC is equal to a depth-dose curves of the original linac. That means that the DMLC affects only the off-axis ratio (OAR). Due to the double-focused construction of DMLC, the penumbras of fields with DMLC are independent from the field sizes. The DMLC shows transmission below to 1%. Because of this minimal transmission, the linac jaws can be fixed while the DMLC is moving. It enhances the sparing of normal tissue by minimizing unwanted dose exposure. In this paper, the dosimetric investigations proved the applicability of the DMLC attached to the Elekta Synergy linear accelerator.

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이중으로 집중된 동적 미세 다엽콜리메이터의 선량학적 특성 평가

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이중으로 집중된 미세 다엽콜리메이터(Double-focused micro Multileaf Collimator: μMLC)는 보통의 다엽콜리메이터(Multileaf Collimator: MLC)에 비하여 조사면 가장자리 부분의 선량을 급격하게 줄여준다. 이러한 특성 때문에, 미세 다엽콜리메이터는 정위적 방사선 수술과 치료(Stereotactic Radio-Surgery/RadioTtherapy, SRS/SRT)에 사용되어 왔다. 우리는 Elekta Synergy 선형가속기에 이중으로 집중된 동적 미세 다엽콜리메이터(Double-focused Dynamic micro-Multileaf Collimator: DMLC)를 부착하여 선량학적 특성을 평가하였다. 본 연구에서는, 필름(GafChromic EBT2 film), EDGE 다이오드 검출기, 3차원 물 팬텀을 이용하였다. 깊이선량백분율(Percent Depth Dose, PDD), 엽 투과도(leaf leakage), 반그림자(Penumbra)를 측정하였고, 모든 데이터들은 6MV 광자선으로 측정하였다. 그 결과, DMLC가 1% 이내의 투과도를 갖는 것을 확인할 수 있었다. DMLC는 이중으로 집중 되는 구조를 가졌기 때문에 반 그림자가 조사야 크기에 대하여 독립적인 것을 확인하였다. 본 연구에서는 DMLC의 선량학적 특성을 바탕으로, Elekta Synergy에 부착된 DMLC의 적용 가능성을 증명하였다.

중심단어: 동적 미세다엽콜리메이터, 깊이선량백분율, 엽 투과도, 반그림자