PMP

Original Article

Progress in Medical Physics 29(2), June 2018
https://doi.org/10.14316/pmp.2018.29.2.66
eISSN 2508-4453

Verification of Mechanical Leaf Gap Error and VMAT Dose Distribution on Varian VitalBeam^{TM} Linear Accelerator

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Received 28 May 2018
Revised 12 June 2018
Accepted 20 June 2018

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The proper position of a multi-leaf collimator (MLC) is essential for the quality of intensity-modulated radiation therapy (IMRT) and volumetric modulated arc radiotherapy (VMAT) dose delivery. Task Group (TG) 142 provides a quality assurance (QA) procedure for MLC position. Our study investigated the QA validation of the mechanical leaf gap measurement and the maintenance procedure. Two VitalBeam^{TM} systems were evaluated to validate the acceptance of an MLC position. The dosimetric leaf gaps (DLGs) were measured for 6 MV, 6 MVFFF, 10 MV, and 15 MV photon beams. A solid water phantom was irradiated using 10×10 cm^2 field size at source-to-surface distance (SSD) of 90 cm and depth of 10 cm. The portal dose image prediction (PDIP) calculation was implemented on a treatment planning system (TPS) called Eclipse^{TM}. A total of 20 VMAT plans were used to confirm the accuracy of dose distribution measured by an electronic portal imaging device (EPID) and those predicted by VMAT plans. The measured leaf gaps were 0.30 mm and 0.35 mm for VitalBeam 1 and 2, respectively. The DLG values decreased by an average of 6.9% and 5.9% after mechanical MLC adjustment. Although the passing rates increased slightly, by 1.5% (relative) and 1.2% (absolute) in arc 1, the average passing rates were still within the good dose delivery level (>95%). Our study shows the existence of a mechanical leaf gap error caused by a degenerated MLC motor. This can be recovered by reinitialization of MLC position on the machine control panel. Consequently, the QA procedure should be performed regularly to protect the MLC system.

Keywords: Optimization of mechanical leaf gap, Dosimetric leaf Gap, PDIP calculation

Introduction

Multi-leaf collimators (MLCs) are essential components of intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) for shaping a radiation beam along a treatment field. MLC was introduced clinically to deliver static field treatments and have recently been used in intensity modulated field treatments with dynamic multi-leaf collimation.[1] Since then, related MLC technologies have been rapidly developed in terms of MLC design characteristics and techniques of leaf position control. An accuracy of dose delivery in radiotherapy depends upon appropriate accounting of the MLC characteristics such as shape of leaf ends, leaf transmission, leaf scatter, and collimator scatter upstream from the MLC.[2]

Technically, the shape of the leaf ends differs from one manufacturer to another. Single-focused leaves (Electra and Varian) are rounded while double-focused leaves

(Siemens) have flat leaf ends. Varian introduced the single focused leaves, which have round shaped leaf ends and tongue-and groove.[3] The rounded leaf ends are designed to reduce a wider penumbra width generated from flat leaf edges. The degree roundedness of the leaf ends is determined by considering beam divergence while the leaf tips are positioned at various distances from the central isocenter across the field. A transmitted radiation leakage is induced through the two rounded leaves referred to the dosimetric leaf gap (DLG).[4,5]

There are several issues with the QA program related to the MLC system. It is not only the MLC position but also the mechanical leaf gap width between a pair of leaves. Varian's specification defines that the mechanical leaf gap width between the two opposing flat sides should be 0.5 mm. Inaccurate leaf gap width may lead to problems such as undetectable micro collision. This mechanical impact may cause failure of individual motor. In recent times, we experienced several MLC motor breakdowns due to mechanical errors of MLC gaps. However, this problem has been solved by MLC gap adjustment by re-initializing the resetting of all MLC encoders.

In this study, the focus is on appropriate maintenance for optimizing MLC leaf gap width in radiation treatment system. It is a specific QA procedure supported by the manufacturer. We investigated validation of the mechanical measurement of the leaf gap width and the reinitialization procedure of a millennium 120 MLC system in Varian VitalBeam™ system.

Materials and Methods

1. Mechanical MLC gap revision

The leaf gap width of MLCs was mechanically measured and adjusted on two Varian VitalBeam™ (Varian Medical Systems, Palo Alto, CA) linear accelerators mounted with millennium 120 MLC system. Two linear accelerators have been properly commissioned and maintained in accordance with AAPM Task Groups (TGs) specifications. For measuring the leaf gap width mechanically, the gantry head was set to 180 degree to open MLC system and 2 opposing leaves were aligned along the central axis to measure the leaf gap width. A filler gauge, which consists of metal plates of varying thicknesses (Fig. 1(b)), was inserted, one plate at a time from thinner to thicker, into the gap of aligned MLCs to measure the leaf gap width. Mechanical differences of MLC gap corresponding to the tested linear accelerators were precisely adjusted to 0.5 mm by changing the gap value on the machine control panel.

2. DLG assessments

For the evaluation of accuracy of the obtained leaf gap values, the DLGs of two MLC systems were investigated before and after the mechanical calibration. We performed the DLG measurement as per a method suggested from Varian's guideline. Measurements were implemented for 6 MV, 6 MV-flattening filter-free (FFF), 10 MV, and 15 MV photon beams in 30×30 cm^2 solid water phantom (Standard

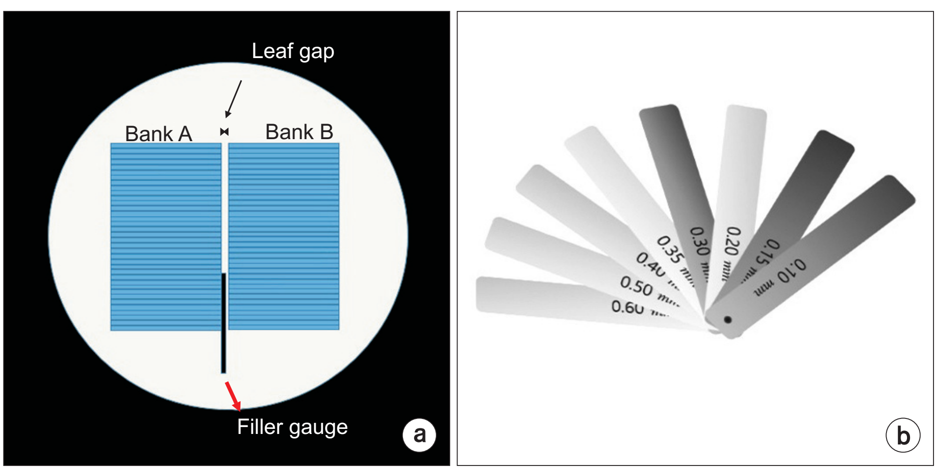

Fig. 1. Mechanical multi-leaf collimator (MLC) gap measurement. (a) Millennium 120 MLCs of VitalBeam™ accelerator in a 180° rotated position for measuring actual leaf gap width (b) a filler gauge used for leaf gap width assessment.

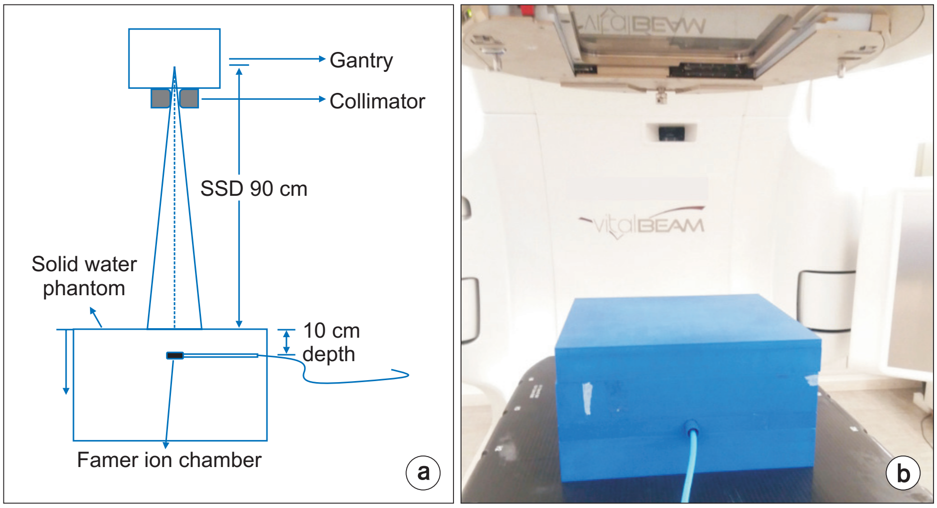

Fig. 2. The dosimetic leaf gap (DLG) measurement using ionization chamber and solid water phantom: (a) schematic design and (b) solid water phantom (30 cm×30 cm), and famer ion-chamber on a couch in VitalBeam™.

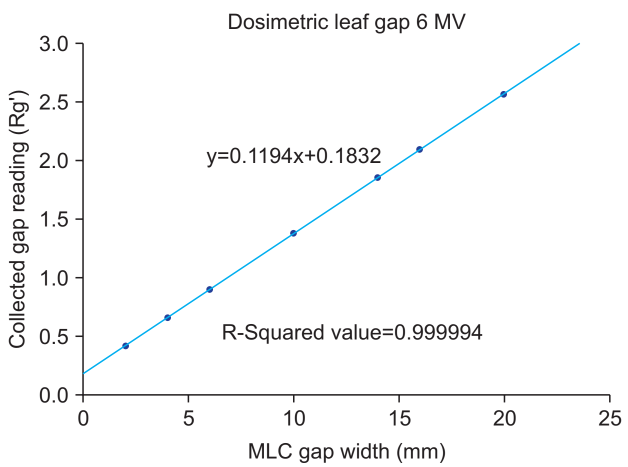

Fig. 3. Example of predicted linear dependence for 6 MV photon beam and equation for obtaining the absolute value of b in order to seek the dosimetric leaf gap (DLG).

Imaging, Middleton WI, USA) at 90 cm source to surface distance. The Farmer ionization chamber (PTW, Germany) with 0.6 cm^3 was placed at 10 cm depth within the solid water phantom and was irradiated using a 10×10 cm^2 field size. DLG are commonly measured with distinct uniformed extension of synchronized dynamic MLC sweeping gap field. The DLGs were measured with 2, 4, 6, 10, 14, 16, and 20 mm MLC gap widths and the gaps moved from –60 mm to +60 mm at a constant speed with respect to 100 MU to a delivery dose.

Various methods for measuring a DLG size were suggested in several studies.[6,7] We used a methodology described by LoSasso et al.[1] DLG is obtained from the graph in which the corrected gap reading is plotted against each tested gap size width (mm). A predicted trend-line is defined as g(Rg') = aRg'+b to points given by gap size g and corrected gap reading R_g'.[8] The intercept value of b is the DLG and to obtain DLGs, corrected gap reading (R_g') for each gap (mm) is calculated using the following equation.

$$R_g' = R_g - R_{gT} \quad \text{.............................} (1)$$

where R_g is a real reading value corresponding to each gap size, and R_{gT} is the average MLC leaf transmission for each gap. It is obtained from the following equation.

$$R_{gT} = R_T \cdot \left[1 - \frac{g[mm]}{120[mm]}\right] \text{.....................} (2)$$

R_T is the average transmission reading, which is calculated as follows.

$$R_T = \left[\frac{(R_{T,A} + R_{T,B})/2}{R_{open}}\right] \cdot R_{open} \text{.....................} (3)$$

where $R_{T,A}$ and $R_{T,B}$ represent the MLC transmission reading for MLC bank A and B. R_{open} is the dose measured for open field.

3. Calculation of PDIP (portal dose image prediction)

To evaluate the MLC system for VMAT beams, we performed an evaluation using a comparison of difference between the dose distribution calculated from treatment planning system (TPS) and that actually delivered. We obtained the predicted dose from a PDIP algorithm to VMAT beams and the computational prediction was implemented on commercially available treatment planning system (TPS) which is Varian's Eclipse™ (Varian Medical Systems, Palo Alto, CA). The TPS PDIP algorithm in the software tool utilized an incorporated correction factors to generate the predicted electronic portal imaging device (EPID) image to account for the difference in EPID response to the open beam radiation and MLC transmitted radiation. The EPID is being used in radiotherapy to achieve an accurate dose assessment. First, it produces images almost instantaneously and saves the images digitally on a computer. Second, it is available as a treatment field verification during the treatment gives the quality treatment. Third, images will be available immediately for reference and so on.[10)]

VMAT plans with two full arcs, which were previously used for patient treatments, were retrospectively selected. A total of 20 VMAT treatment plans corresponding to the two VitalBeam™ linear accelerators were analyzed in this study. The treatment sites were various, which were brain, head and neck (H&N), and prostate. This evaluation process was performed twice, before and after the mechanical measurement and a correction of the MLC gap position. Dose agreement between the PDIP and the acquired EPID image was analyzed by using global gamma (r) passing rates proposed by Low et al.[11)] The Gamma passing rate has the criteria of 3%/3 mm, and a value of 95% or more is considered to be clinically accepted value.[9,12,13)] A mean gamma pass rate was analyzed on a relative, absolute, and composite dose difference.

Table 1. The measured dosimetric leaf gap (DLG) result with an ionization chamber in VitalBeam 1.

Machine	Energy	Dosimetric leaf gap (mm)		Difference (mm)
		Before	After	
VitalBeam 1	6 MV	1.65	1.54	−0.11
	6 MVFFF	1.16	1.38	0.62
	10 MV	1.88	1.39	−0.49
	15 MV	1.73	1.67	−0.06
Average		1.60	1.49	−0.11

Results

1. DLG assessment

The mechanically measured MLC gap distances of 0.3 mm and 0.35 mm correspond to the VitalBeam 1 and 2, respectively. The gap sizes measured using the filler gauge were closer than optimal size, 0.5 mm. Table 1 and 2 summarize the results of DLG value measured with ionization chamber, and compare the variation between the results before and after the mechanical correction. A transmitted dose distribution was measured for a 10 cm×10 cm MLC field at 10 cm depth using a Farmer ion-chamber. Fig. 1 displays a trend-line of measured DLG values corresponding to the corrected gap reading at points. The tested MLC sliding points were 2, 4, 6, 10, 14, 16, and 20 mm. The DLG sizes for 6 MV low energy beam tend to be slightly decreased from 1.650 (before calibration) to 1.536 mm (after calibration) in both the machines. The DLG value of 10 MV photon beam is also reduced from 1.875 mm to 1.389 mm in VitalBeam 1 (1.485 mm in VitalBeam 2). The differences of DLG values for the 6 MVFFF increased as a 0.62 mm and 0.23 mm to both the VitalBeam™ systems. In 15 MV beam of VitalBeam 1, a little difference between before and after is tabulated in Table 1. Average deviations of DLG values between pre and post MLC correction were 0.11 mm (6.9% decreased) and 0.09 mm (5.9% decreased) in the two linacs, respectively. The results show that no significant difference was found between the two linear accelerators ($P<0.01$).

2. PDIP calculation

Table 3 and 4 summarize the results of the PDIP calculation in order to validate the accuracy of MLC leaf position.

Table 2. The measured dosimetric leaf gap (DLG) result with an ionization chamber in VitalBeam 2.

Machine	Energy	Dosimetric leaf gap (mm)		Difference (mm)
		Before	After	
VitalBeam 2	6 MV	1.65	1.54	−0.11
	6 MVFFF	1.16	1.39	0.23
	10 MV	1.88	1.49	−0.39
Average		1.56	1.47	−0.09

Table 3. Averaged gamma passing rate results measured on relative and absolute dose calculation to VitalBeam 1.

Machine VitalBeam 1 (n = 10)	Relative (%)			Absolute (%)		
	Arc 1	Arc 2	Composite	Arc 1	Arc 2	Composite
Pre-MLC correction	99.5±0.8	98.8±2.3	99.9±0.1	99.5±0.8	99.5±0.6	99.3±0.7
Post-MLC correction	98±2.4	97.4±2.2	98.1±1.9	98.3±1.6	98.4±1.3	96.8±2.8
Difference (%)	1.5	1.4	1.8	1.2	1.1	2.5

Table 4. Averaged gamma passing rate results measured on relative and absolute dose calculation to VitalBeam 2.

Machine VitalBeam 2 (n = 10)	Relative (%)			Absolute (%)		
	Arc 1	Arc 2	Composite	Arc 1	Arc 2	Composite
Pre-MLC correction	99.3±1.4	99±1.6	99.9±0.2	98.2±2.1	98.6±0.9	96.9±3.2
Post-MLC correction	97.8±3.7	98.9±1.5	99.3±0.7	98.7±1.3	99±0.7	98±1.9
Difference (%)	1.5	0.1	0.6	0.5	0.4	1.1

The calculated passing rates were obtained with Eclipse™ and this software tool used the DICOM RT image from the EPID. Two VMAT arcs were acquired to verify the validation of MLC and plan data from ten patients were utilized for this evaluation. Averaged passing rates of VitalBeam 1 with relative analysis decreased from 99.5%±0.8% to 98.8%±2.4% in VMAT arc 1. It decreased slightly to 98.8%±2.3% and 97.4%±2.2% in arc 2 also, as tabulated in Table 3. Table 4 shows that VitalBeam 2 also exhibited a small reduction in the averaged passing rate, which is similar to that of VitalBeam 1. Mostly the average gamma passing rates were slightly reduced after the mechanical leaf correction in Table 3 and 4. However, the validity of passing rate was still within the good dose delivery level (>95%). Furthermore, a composite calculation of the VMAT arc 1 and 2 shows no significant difference between VitalBeam 1 and VitalBeam 2 (P<0.05).

Discussion

In this study, MLC system was investigated to validate the QA procedure of mechanical MLC leaf gap. The evaluated DLG values with 6 MV, 10 MV, and 15 MV were reduced from an MLC correction but it was not so with the 6 MVFFF. The DLG size with 6 MVFFF was lower than that of the other beams. This is because a flattening filter free causes softening of beam spectrum and it can lead to a reduction in DLG value.[14] After the MLC correction, the leaf gap increased from 0.3 mm to 0.5 mm. It tends to increase the DLG size in case of the flattening filter free. The results of PDIP calculation showed gamma passing rates within a criterion 3%/3 mm. Thus, the processed MLC leaf correction is valid for a QA procedure to VitalBeam™ system.

Resolutions of MLC system define the quality of the IMRT and VMAT dose delivery.[1] VitalBeam™ has a rounded end Millennium 120 MLC and it is designed to reduce immoderate wider penumbra caused from flat-type leaf edges.[4] Although this design can reduce the penumbra size, and it can lead to a significant dose variation between treatment planning and delivered dose distributions. The variation is affected by a beam transmission that passes through from the rounded leaf end to leaf end along the vertical axis of MLCs. The beam transmission through the rounded leaf MLC is also known as the DLG, and it is also referred to as radiation offset (RFO).[6] To date, the DLG was typically estimated to define the quality of MLC system in terms of the transmitted radiation and practically delivered dose distribution. On the other hand, we have experienced several failures with MLC motor in recent times, which indicated that the problem is related to the leaf gap width between the two opposing leaf sides. Varian informed that the leaf gap width is properly to be 0.5 mm. Although all performance to VMAT dose delivery with two VitalBeam™ systems were properly maintained on our QA program followed the AAPM TG-.40, 45, 51, 53, 114, and others, the mechanical measurement of leaf gap width showed a slightly narrower value than 0.5 mm in both linacs. Indeed each individual MLC leaf is moved by the MLC motor and this movement affects the gap width for individual leaf pairs. This problem is related to the usage amount of the individual leaf motors.[15] In our case, the gap was considerably closed and this situation may lead to an undetectable microcollision on the leaves. The collision will return a certain impact to the MLC motor. This problem can be temporarily relieved by reinitialization of resets of all encoders.[16]

Conclusion

We investigated the validation of MLC system using a tool in order to check a mechanical leaf gap width. Our study shows that there is a mechanical leaf gap error caused by a degenerated MLC motor. Although the problem is not significant as it does not decrease the accuracy of VMAT dose delivery, but it may cause breakdown of MLC motor. This can be recovered by reinitialization of resets of all encoders in MLC system. Consequently, the QA procedure for the mechanical leaf gap measurement should be performed regularly to prevent the MLC motor failure.

Acknowledgements

This study was supported by the National Research Foundation of Korea (NRF) grant, funded by the Korean government (MSIT: Ministry of Science and ICT) (No. NRF-2017M2B2A4048622) and a VHS Medical Center Research Grant, Republic of Korea (grant number: VHSMC 18031).

Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

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