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Measurement methods for positioning accuracy of multileaf collimators in radiation therapy: A mini review

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Highlights

- A comprehensive review of the structure, 3D and 2D views, operational principles, and major manufacturers of multileaf collimators (MLCs) used in radiation therapy.
- Introduction and comparison of three methods for evaluating the positioning accuracy of MLCs: dose film mea surement system, Matrixx ionization chamber array, and electronic field imaging system.

Abstract

Radiation therapy is a complex and high-precision technique that requires strict performance criteria for linear accelerators. One of the key factors influencing the quality of radiotherapy is the positioning accuracy of each leaf of the multileaf collimator. This mini-review discusses three commonly used dosimetry-based methods for evaluating multileaf collimator positioning accuracy: the dose film method, the Matrixx ionization chamber array method, and the electronic portal imaging device method. The review highlights the differences between these methods, showing that both the electronic portal imaging device and Matrixx methods offer higher measurement repeatability compared to the dose film method. However, the electronic portal imaging device method is more complex to implement than the Matrixx method.

Keywords: Positioning accuracy, multi leaf collimators, radiation therapy

Introduction

Radiation therapy has revolutionized cancer treatment by significantly increasing the radiation dose delivered to tumors while minimizing exposure to organs at risk, thereby improving tumor control rates. Achieving optimal outcomes in radiation therapy requires high-precision irradiation techniques and stringent performance standards for linear accelerators. A critical factor affecting the success of radiation therapy is the positioning accuracy of each leaf in the multileaf collimator (MLC) [1, 2].

An MLC is a beam-limiting device composed of multiple independent "leaves" made from high atomic number materials, typically tungsten. These leaves can move individually to shape and modulate the intensity of the radiation beam. MLCs are used in external beam radiotherapy to deliver conformal radiotherapy and intensity-modulated radiation therapy [3, 4]. Due to the high precision required in shaping the dose, as well as the dynamic changes in gantry speed and dose rate during intensity-modulated radiation therapy and volumetric

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Table 1. Comparisons of the MLC performance across difference companies

Company	Type	Positioning Accuracy (mm)	Number of Leaves	Leaf Thickness (mm)	Field Size (mm×mm)
Varian Corp.	Millennium 120	±1	120	5	400×400
	HD 120	±1	120	2.5	220×400
	Halcyon	±1	114	10	280×280
Elekta Corp.	MLCi/MLCi2	±0.5	80	10	400×400
	Apex mMLC	±0.25	112	2.45	120×140
Siemens Corp.	MLC-82	±0.3	82	10	400×400
OUR United Corp.	TaiChi-120	±0.3	120	5	400×400

Note: MLC, multileaf collimator; HD, high definition.

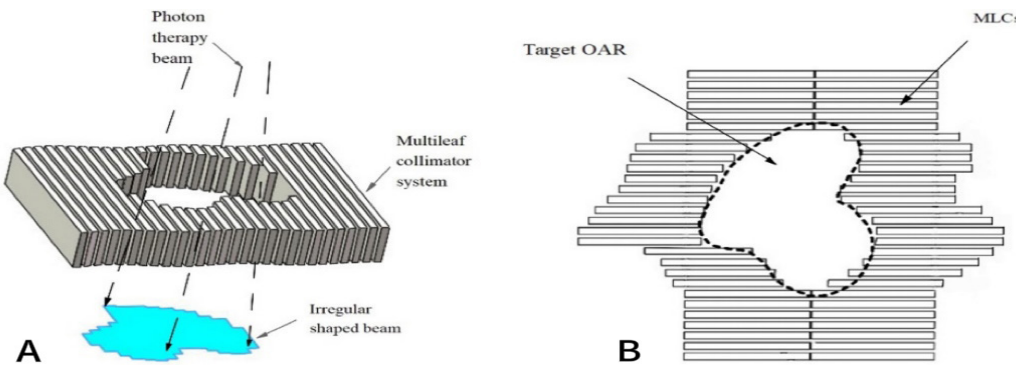

Figure 1. Principle of the MLCs. (A) 3D view of the MLCs; (B) 2D view of the MLCs. MLCs, multileaf collimators; OAR, organs at risk.

modulated arc therapy treatments, patient-specific pretreatment quality assurance is essential. Even minor deviations in MLC leaf positions can lead to significant inaccuracies in dose distribution, affecting the intended doses to the tumor and organs at risk [5-7]. For example, Rangel et al. reported that a 1 mm deviation in MLC leaf positioning could result in dose differences of up to 5.6% in the equivalent uniform dose for clinical target volumes in head and neck cancer treatment plans [7].

The MLC is primarily composed of multiple leaf pairs, as illustrated in **Figure 1**, with a 3D view in **Figure 1A** and a 2D view in **Figure 1B**. The position of the MLC leaves is adjusted based on the target area, allowing the radiation beam to be shaped according to the projection of the target on the irradiation plane. In practical applications, the leaves are driven by micromotors, which convert rotational motion into linear leaf movement through a screw mechanism. To ensure accurate leaf positioning, the speed, acceleration, and number of rotations or steps of the driving motors are precisely controlled, often using an encoder to monitor and regulate each motor's movement [8, 9].

Leading manufacturers of radiation therapy equipment include Varian, known for its advanced radiation therapy solutions [8, 9]; Elekta, which offers versatile linear accelerators with artificial intelligence (AI)-enhanced imaging and adaptive capabilities [10]; and Siemens, which has developed systems to aid in radiation therapy planning. OUR United Corporation, a specialized company based in Xi'an, China, focuses on the research, development, production, and service of innovative technologies and equipment for tumor radiotherapy [11-15]. **Table 1** compares the MLC performance metrics, including positioning accuracy, number of leaves, leaf thickness, and field size, across different manufacturers [11-15].

Currently, there are three primary dosimetry-based methods for detecting MLC positioning accuracy: the dose film measurement system, the MatriXX ionization chamber array, and the electronic portal imaging device (EPID) [16, 17].

Primary dosimetry-based methods

Dose film measurement system

This method utilizes Kodak X-OMAT V film, which is enclosed in an opaque envelope and processed using an automatic film processor. The film is scanned with a VIDAR DosimetryPro Advantage film scanner, and data is analyzed using RIT113 film analysis software. **Figure 2** illustrates the solid water phantom used for radiotherapy validation. Constructed from poly-

Table 2. Coordinates of reference leaves in place (mm)

Measurement method	50×200		100×200		150×200		200×200	
	X1	X2	X1	X2	X1	X2	X1	X2
Dose film	24.6	25.3	49.5	50.3	74.9	75.3	99.5	100.3
MatriXX	24.3	25.4	49.4	50.5	74.6	75.7	99.8	100.6
EPID	24.8	25.3	49.7	50.3	74.7	75.3	99.2	99.9
Maximum difference	0.5	0.1	0.3	0.2	0.3	0.4	0.6	0.7
Mean and standard deviation	0.39±0.20							

Note: EPID, electronic portal imaging device.

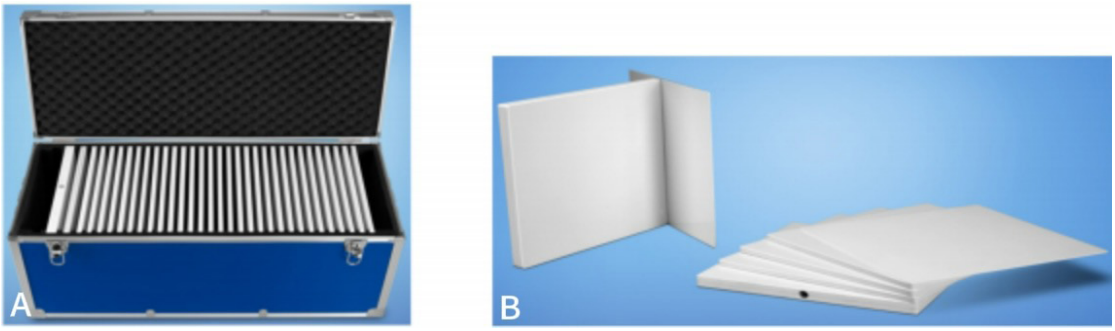

Figure 2. Delta instruments radiotherapy verification solid water phantom SRT-033. (A) Solid water phantom in a test chamber; (B) Layers view with different thickness. This figure is cited from [18].

styrene, the phantom measurs 300 mm × 300 mm, and consists of 29 layers of 10 mm thickness, along with one layer of 5 mm thickness, two layers of 2 mm thickness, and one layer of 1 mm thickness. To perform optical density calibration with this method, follow these steps [18]:

(1) Set the source-to-skin distance to 100 cm and place a 2 cm thick solid water phantom on the film. Set the irradiation field to 4 cm × 4 cm.

(2) Expose the film to 8 different dose fields at various positions. Record the average optical density for each field center.

(3) Use segmented polynomial fitting software to establish a dose-response curve from these recordings. Draw a crosshair at the geometric center of the film before exposure and align it with the light field to determine the field center.

(4) Create leaf position templates for the four fields mentioned above in the RIT113 software. Input the processed validation films into RIT113 using the DosimetryPro Advantage film scanner.

(5) Utilize the established template file to analyze the accuracy of each picket position by measuring the center position of the 51% dose line between each pair of pickets.

MatriXX ionization chamber array

The MatriXX ionization chamber array from IBA, Germany, is used for this method, as shown in **Figure 3**. Each chamber is factory-calibrated to ensure consistent measurement results. IBA's OmniPro I'mRT software is used for data collection and analysis of accelerator field dose data [18]. The procedure for this method involves the following steps [18]:

(1) Position the MatriXX array horizontally under the accelerator and align its effective measurement surface with the isocenter plane using a laser lamp. Place a 2 cm thick solid water phantom on the isocenter plane.

(2) Open the accelerator beam to a 25 cm × 25 cm field size and preheat the MatriXX array with continuous beam output, monitoring for consistent response from each chamber

(3) Once preheated, collect four field shapes using the Movie mode. Use the Multiple Row Analysis function in OmniPro I'mRT software, a user-friendly application for comprehensive plan verification and quality assurance of intensity-modulated radiation therapy, IGRT, and rotational treatments. Analyze the positioning accuracy of each pair of pickets, applying the Fermat interpolation algorithm to accurately detect the edges of the radiation field.

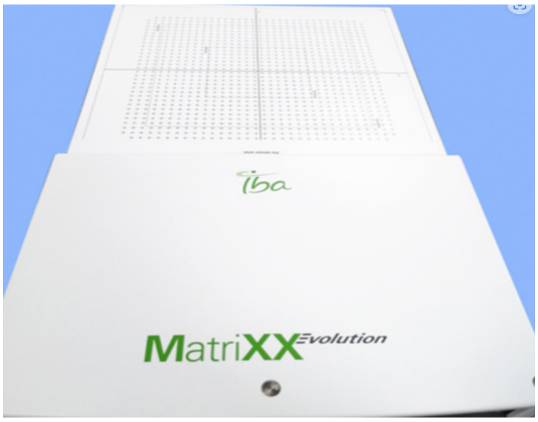

Figure 3. IBA MatriXX 2D Array.

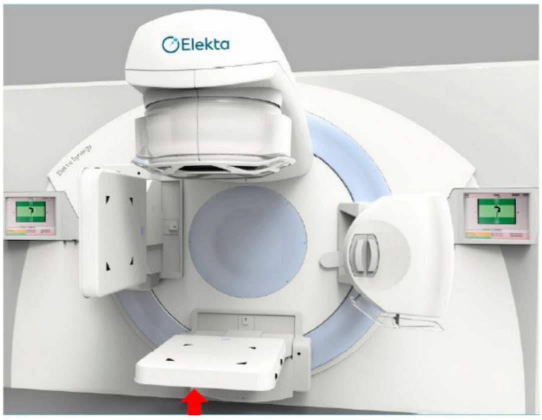

Figure 4. The Elekta Synergy Linear Accelerator.

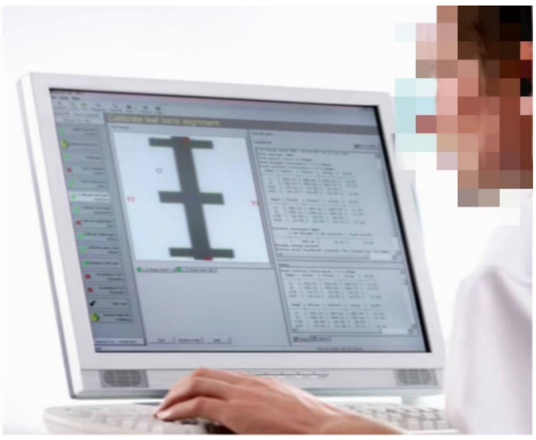

Figure 5. Graphical user interface of AutoCAL software.

Electronic field imaging system

This method employed the electronic field imaging system, known as IView GT, developed by Elekta — a global Swedish company specializing in radiation therapy and radiosurgery equipment, as well as clinical management for treating cancer and brain disorders [19-21].

The IView GT system consists of an amorphous silicon detector array with an effective imaging area of 26 cm × 26 cm at the isocenter. The measurement range can be extended through electronic translation in the G-T (gantry-tilt) and A-B (anterior-posterior) directions of the accelerator. It supports energy levels from 4 to 20 MV and a dose rate range of 50 to 600 MU/min [19-21]. Data collection and analysis are conducted using IBA's AutoCAL software (Ion Beam Applications) [19-21]. **Figure 4** shows the IView GT amorphous silicon detector panel, and **Figure 5** displays the AutoCAL software interface. The following steps should be performed according to AutoCAL software requirements before measurement:

(1) Align the small machine head of the accelerator parallel to the detection panel.

(2) Calibrate the pixel size of the IView GT detector panel.

(3) Set a radiation center as a reference point for measuring absolute dimensions.

(4) Align the machine center, represented by the crosshairs of the small machine head, with the radiation center.

After completing these steps, the AutoCAL software's Size Test function could be used to collect data from four fields for analysis.

Discussion

Table 1 presents the measurement results for a pair of leaves of the same accelerator at different positions using the three measurement methods. The maximum difference in results among these methods is less than 1 mm. The measurement outcomes for all other leaves are consistent with **Table 2**, and the maximum difference for each group of leaves across different field sizes is also less than 1 mm. This indicates that all three methods can effectively perform quality assurance testing on the MLCs of the same accelerator, with largely consistent results. Generally, the dose film measurement system exhibits lower measurement repeatability, while the MatriXX ionization chamber array and the electronic field imaging system demonstrate higher repeatability.

The positioning accuracy of MLCs is a critical factor influencing the success of radiotherapy. High-performance standards for accelerators are essential for the precise and complex irradiation procedures required in radiation therapy.

Conclusion

This paper provides a brief review of three commonly used dosimetry-based methods for detecting MLC positioning accuracy: the dose film measurement system, the MatriXX ionization chamber array, and the EPID. Among these, the EPID and the MatriXX ionization chamber array offer higher measurement repeatability compared to the dose film measurement system. However, the EPID is more complex to set up and requires more sophisticated software than the MatriXX ionization chamber array.

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