IMPACT OF DIFFERENT VARIABLES ON DOSIMETRIC LEAF GAP MEASUREMENT IN ROUNDED LEAF END MLC SYSTEMS

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Abstract: **This research aims to evaluate the dosimetric leaf gap (DLG) utilizing Integral sliding fields doses with varying gap widths for linear extrapolation to zero dose and intersection at the gap width axis. The study employs a 0.13 cc ionization chamber, Dose-1 electrometer, and water equivalent slab phantom. Experiments are conducted on a Varian True Beam linac equipped with the 120 Millennium MLC and Eclipse™ Treatment Planning System (TPS), examining different depths, photon beam energies, Source to Surface distances (SSDs), chamber orientations, and dose rates. Findings indicate that the DLG value remains consistent regardless of measurement orientation from the sweeping beam direction. The standard deviation (SD) values for varying SSDs, dose rates, and measurement depths are 0.061758%, 0.104595%, and 0.057940% respectively. DLG increases with higher photon beam energies, measuring 1.14537 mm, 1.27057 mm, and 1.30293 mm for 6 FF MV, 10 FF MV, and 15 FF MV respectively. Accurate DLG values within the TPS are crucial for precise dose calculations, particularly when applied to small targets using the DMLC delivery technique in IMRT, IGRT, SRS, and SBRT.**

Keywords: **dosimetry leaf gap, treatment planning system, leaf transmission, DMLC**

I. INTRODUCTION

The primary objective of radiotherapy is to deliver radiation to a target area while minimizing exposure to healthy tissues. Beam shaping plays a crucial role in reducing radiation absorption by healthy cells and vital organs. While conventional collimator jaws create rectangular treatment fields, additional shaping is necessary as treatment volumes are not typically rectangular [1]. Linear accelerators utilize Cerrobend blocks attached to the treatment head beneath a standard collimating system. However, beam blocks have several drawbacks, leading to the revolutionary introduction of multileaf collimators (MLC) since the late 1980s. The multileaf collimator is an important new tool for radiation therapy dose delivery [2]. MLCs aim to provide conformal therapy and enhance treatment delivery effectiveness, resulting in improved outcomes. An MLC is a beam-limiting device comprising numerous collimating leaves that can be independently and automatically controlled to generate any desired field shape. MLC field shaping is expected to reduce patient setup time during treatment and lower operational costs. This technology results in rounded leaf-end transmission [3] when the leaves are fully closed.

In the IMRT plan's leaf ordering process, the Leaf Motion Calculator (LMC) transforms the optimal fluence into a sequence that can be achieved by [4] the multileaf collimator (MLC). During this process, a parameter known as the Dosimetric Leaf Gap (DLG) is used to account for the disparity between dosimetric and geometric field widths caused by partial transmission through two adjacent rounded leaf ends of the MLC [5,6]. The DLG represents the gap between the physical leaf end and its dosimetric counterpart.

The Varian Eclipse dose calculation requires [7] this parameter to accurately simulate field modulation. Varian linear accelerators utilize rounded MLC leaf ends [8] to enhance off-axis dosimetric characteristics. The treatment planning system (TPS) approximates the MLC as having straight edges and accounts for the actual rounded leaf end transmission by retracting the leaf end by half the DLG value. MLC-formed fields exhibit specific penumbra compared to jaw-formed fields. The rounded leaf end structure influences the lateral penumbra, while the tongue and groove structure affect the longitudinal penumbra [9]. The measured DLG addresses the lateral penumbra, but the longitudinal penumbra has minimal impact on this DLG due to the larger field size in this direction [10]. However, typical IMRT/VMAT patient plans often include segments with small longitudinal field sizes. A precise DLG value could compensate for both the dose from the leaf gap to the longitudinal penumbra and the dosimetric inaccuracies associated with small fields (gaps).

In contrast, the Eclipse system's AAA photon dose calculation algorithm only requires two parameters per energy for its calculations [8]: (1) the Dosimetric Leaf Gap (DLG) and (2) the mean transmission factor through closed leaves, which encompasses both interleaf leakage and leaf transmission [11]. As a result, minor changes in MLC gaps (DLGs) could lead to significant discrepancies between the TPS calculated dose and the actual dose delivered to the patient [12]. Consequently, the optimal DLG value is integrated into the Eclipse TPS to ensure accurate dose calculations. This parameter is crucial for the Varian Eclipse dose calculation to precisely model field modulation.

The dosimetric leaf gap (DLG) is affected by X-ray transmission [13-15] through the rounded leaf ends, with its value contingent on beam quality and multi-leaf collimator (MLC) type. Typically, DLG values are established for each beam energy during the commissioning process. Multiple studies indicate that the DLG is dependent on various factors, including [16]: 1) MLC leaf positioning precision: Deviations in leaf positions can lead to discrepancies between planned and delivered doses. 2) Beam energy: The DLG is affected by X-ray transmission via the rounded leaf ends, making its value dependent on beam energy [17]. 3) Radiation field dimensions and configuration: The size and shape of the field can impact the DLG. 4) Measurement technique: Different methods, such as ionization chamber or diode measurements, can be employed to determine the DLG, and the chosen method may influence the resulting value.

Dosimetric impact of the DLG:

The dosimetric impact of DLG in treatment planning systems and the experimentally determined DLG value demonstrate significant variations, deviating from the two expected outcomes.

1) If $DLG_{Measured} < DLG_{TPS}$; so MLC pull back is slowly so the measured dose is less than the TPS calculating dose.
2) If $DLG_{Measured} > DLG_{TPS}$; so MLC pullback is highly and the resultant wider effective MLC opening so the measured dose is greater than the TPS calculating dose.

Adjusting the measured physical DLG values proved crucial for reducing dose calculation errors within the investigated system.

II. MATERIAL AND METHOD

The research was conducted using a VARIAN LINAC True Beam SN4378 at The Gujarat Cancer and Research Institute in Ahmedabad. This machine features a millennium 120-leaf MLC. The most convenient method for Varian systems to determine the DLG is the sweeping gap technique, as outlined in Varian Medical System's documentation [14,18]. The DLG was derived using this technique, employing a CC13 ion chamber, DOSE-1 electrometer, and slab phantom. The calculation of DLG values followed the methodology described by LoSasso et al [14]. However, in this study, measurements were taken using a CC13 ion chamber and Varian-provided DICOM files for the sweeping gap measurements [19].

1. Open the DICOM plan file for the energy, primary fluence mode, and MLC model.
2. Measure leaf Transmission including both banks.
   - Extend Bank A fully and measure the MLC transmission through Bank A ($R_{T,A}$).
   - Extend Bank B fully and measure the MLC transmission through Bank B ($R_{T,B}$).

   Calculate the average transmission reading R_T.

   $$R_T = \left(\frac{R_{T,A} + R_{T,B}}{2}\right) \quad (1)$$

   Where $R_{T,A}$ is transmission through Bank A and $R_{T,B}$ is transmission through Bank B.
3. Measure sliding window fields of various gap sizes.
   - This is a dynamic delivery with a consistent gap formed by the MLC bank.

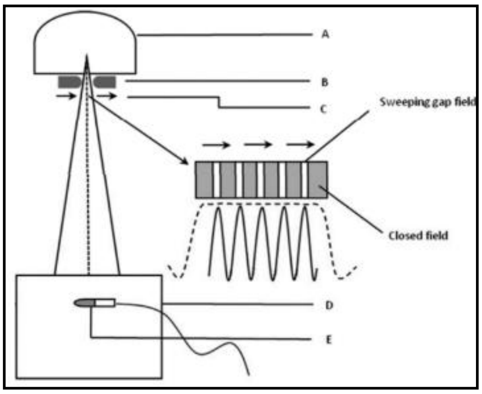

Figure 1: Schematic diagram of DLG measurement using ionization chamber.

(A) Gantry (B) MLC (C) Direction of sweeping beam. The magnified image shows the dose being delivered at different instances of the sweeping beam. A uniform dose is achieved as the result of an integrated dose. (D) Tissue equivalent water slab phantom (E) ionization chamber [4].

- Measurements of integral ionizations were conducted for various nominal gap widths, including 2, 4, 6, 10, 14, 16, and 20 mm. The gap, which swept from −60 mm to +60 mm, maintained a uniform velocity. (refer to Figure1

- To quantify the ionization exclusively resulting from the sweeping gap field, it is essential to eliminate the MLC transmission reading during slit motion, since the chamber was protected by the leaves. Compute the average MLC leaf transmission's influence on the gap reading (RgT) for every gap g calculated from given formula Shende et al. [20]. The transmission's contribution to the gap reading is characterized by:

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

Where R_T is average transmission reading.

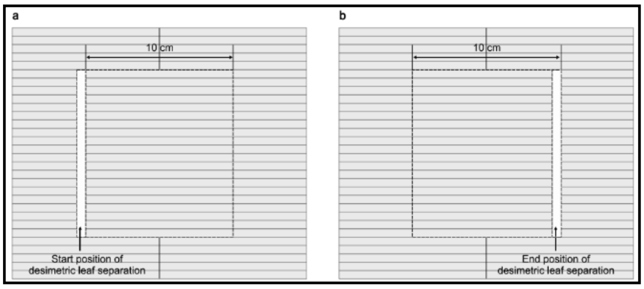

Figure 2: Start (a) and end (b) position of the 10 mm sliding slit movement for dosimetric leaf separation file.

4. Calculate the corrected gap reading for each gap (g) is R_g' using equation (2)

   $$R_g' = R_g - R_{gT} \quad (3)$$

   Where R_g is electrometer reading at gap g and R_{gT} is contribution of transmission to gap reading (g).

5. Determine a linear equation g(R'g) = aR'g + b that aligns with the data points representing the gap size g and the adjusted gap measurement R'g.'.

6. The measured DLG can be determined by graphing the MLC leaf gap in millimeters on the x-axis and the corrected gap reading Rg' in nanocoulombs on the y-axis. The DLG value is represented by the point where the plotted line intersects the horizontal axis.

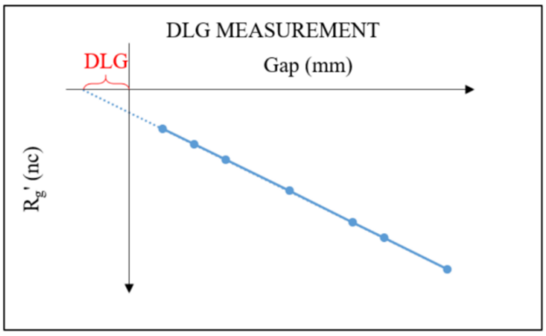

Figure 3: A pictorial representation of DLG measurement as per step 6.

Parameter effect on DLG measurement:

1) To verify the effect of Different orientations of the chamber on DLG measurement:

The CC13 ionization chamber was utilized for DLG measurements in two orientations: perpendicular and parallel to the sweeping beam's direction. Due to slab phantom constraints, the chamber couldn't be physically positioned in the first orientation; instead, the collimator was rotated 90°. Measurements were taken using the SAD technique at a 10 cm depth, delivering 100 MU with a 400 MU/min dose rate. The field size was set to 10 × 10 cm^2, employing 6 FF MV, 10 FF MV, and 15 FF MV photon beam energies. The DLG was calculated using the previously described method. Table (1) illustrates the effect of chamber orientation on DLG measurements.

2) To verify the effect of Different photon beam energy on DLG measurement:

The CC13 ionization chamber was utilized to record DLG measurements, with the linac's photon beam energy potentially influencing dose measurement and, consequently, the DLG value. To investigate the effect of photon beam energy on DLG determination, measurements were conducted using the CC13 ionization chamber at various photon beam energies: 6 FF MV, 10 FF MV, and 15 FF MV. The ionization chamber was positioned at a depth of 10 cm, with a source-to-axis distance (SAD) of 100 cm. A total of 100 MU was delivered at a dose rate of 400 MU/min, with a field size of 10 × 10 cm^2 at the isocenter. The DLG measurement was computed using the previously described method. Table (1) and Figure (1) illustrate the impact of different linac photon beam energies on DLG measurement.

3) To verify the effect of DOSE RATE on DLG measurement:

The CC13 ionization chamber was utilized to record DLG measurements. Since the leaf speed increases with higher dose delivery rates for constant MU settings, the photon beam energy dose rate of the linac could affect dose measurement. Consequently, it is crucial to examine how dose rate impacts DLG. To investigate the effect of photon beam energy dose rate on DLG determination, measurements were conducted using the CC13 ionization chamber. A 6 FF MV photon beam energy delivered 100 MU at dose rates of 400 MU/min and 500 MU/min. The ionization chamber was positioned at a depth of 10 cm, with a SAD of 100 cm and a 10 × 10 cm^2 field size at the isocenter. The DLG measurement was computed using the previously described method. Table (2) illustrates the influence of various photon beam energy dose rates from the linac on DLG measurement.

4) To verify the effect of Different SSDs on DLG measurement:

The source-to-surface distance (SSD) of a linear accelerator can affect dose measurements, consequently impacting the determination of the dosimetric leaf gap (DLG). To investigate how different SSDs influence DLG values, measurements were conducted using a CC13 ionization chamber. The chamber was positioned at a depth of 10 cm, with SSDs of 90 cm and 100 cm. A 6 FF MV photon beam delivered 100 monitor units (MU) at a rate of 400 MU/min. The DLG was calculated using the previously described method. Table (3) illustrates the effect of varying linac SSDs on DLG measurements.

5) To verify the effect of Different depths of measurement on DLG measurement:

The CC13 ionization chamber was utilized to record DLG measurements. The measurement depth of this chamber could potentially impact the dose measurement and, consequently, the DLG value. To investigate the effect of measurement depth on DLG determination, measurements were conducted using the CC13 ionization chamber at various depths. Specifically, the chamber was positioned at 5 cm and 10 cm, with SSDs of 90 cm and 100 cm, respectively. A dose of 100 MU was delivered at a rate of 400 MU/min using a 6 FF MV photon beam. The DLG measurement was then calculated using the previously described method. Table (4) illustrates the influence of different measurement depths on the DLG.

III. RESULTS AND DISCUSSION

DLG vs Energy vs Orientations

For the 6 FF MV photon beam energy, the DLG values derived from the plotted figure were 1.14537 mm for parallel orientation and 1.15844 mm for perpendicular orientation relative to the sweeping field direction, using the CC13 ionization chamber. In the case of the 10 FF MV photon beam energy, the DLG values were found to be 1.27057 mm for parallel orientation and 1.24710 mm for perpendicular orientation. For the 15 FF MV photon beam energy, the DLG values were determined to be 1.30293 mm for parallel orientation and 1.30288 mm for perpendicular orientation, both in relation to the sweeping field direction.

Table 1: Calculate the standard deviation of the CC13 ionization chamber During DLG measurement in the Perpendicular and parallel direction of the sweeping beam for 6 FF MV, 10 FF MV and 15 FF MV photon beam energy.

Chamber orientation	Perpendicular to sweeping beam direction	Parallel to the sweeping beam direction	SD (%)
Photon beam energy	DLG (mm)	DLG (mm)	
6 FF MV	1.15844	1.14537	0.009241
10 FF MV	1.24710	1.27057	0.016595
15 FF MV	1.30288	1.30293	0.000035

DLG vs Energy

As illustrated in the Figure 4, the DLG values obtained using different energy levels of 6 FF MV, 10 FF MV, and 15 FF MV are 1.14537 mm, 1.27057 mm, and 1.30293 mm, respectively.

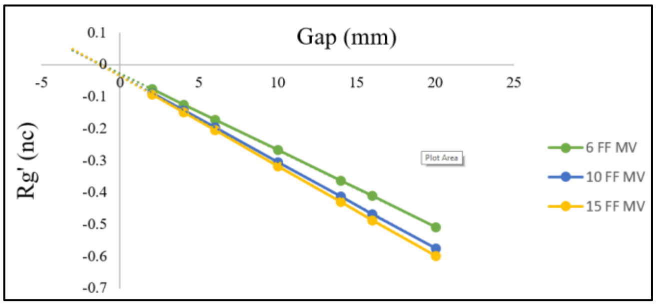

Figure 4: graphical representation of the variation of DLG versus 6 MV, 10 MV and 15 MV photon beam energy.

DLG vs Dose Rate:

The DLG values derived with different dose rates like 400 MU/min, and 500 MU/min, are 1.14537 mm and 1.27057 mm with respectively.

Table 2: DLG value for 400 MU/MIN and 500 MU/MIN photon beam dose rate.

MLC parameter	Dose rate		
	400 (MU/MIN)	500 (MU/MIN)	SD
DLG (mm)	1.14537	1.29329	0.104595

DLG vs SSD

Additionally, the DLG was evaluated at a depth of 10 cm with an SSD of 90 cm and contrasted with a standard SSD of 100 cm to examine the impact of minor alterations in detector distance. A small increase in the distance to the detector did not substantially influence the DLG measurements.

Table 3: DLG value for 90 cm and 100 cm SSD.

MLC parameter	SSDs		
	90 cm	100 cm	SD (%)
DLG (mm)	1.14537	1.05803	0.061758

DLG vs Depth

As shown in Table 4, the DLG values for depths of 5 cm and 10 cm exhibited a slight increase with depth [21], consistent with findings by Zygmanski et al. However, the standard deviation of 0.057940 mm indicated that the difference between depths was insignificant, thus validating the D_{max} measurement.

Table 4: DLG value for 5 cm and 10 cm measurement depth.

MLC parameter	Depth of measurement		
	5 cm	10 cm	SD (%)
DLG (mm)	1.0613	1.14537	0.057940

IV. DISCUSSION

Inaccurate accounting of the DLG can lead to discrepancies between the planned and delivered doses, potentially resulting in under-dosing or over-dosing of the target area and subsequent treatment complications [6]. Underestimating the DLG may reduce the delivered dose to the target, diminishing tumor control probability. Conversely, overestimating the DLG could increase the delivered dose, heightening the risk of radiation toxicity in nearby healthy tissues and organs. As shown in Table 9, DLG characterization is not affected by measurement orientation relative to the sweeping beam direction, variations in source-to-surface distance (SSD), measurement depth, or dose rate. However, it does increase with beam energy due to increase in transmission through the leaf end of MLC [22]. Table 13 demonstrates that when using the CC13 ionization chamber, DLG values rise as photon beam energy increases. Furthermore, MLC systems with reduced scattering and transmitting radiation tend to have smaller DLG values [17].

Although most DLG values reported in literature range from 1.05803 mm to 1.30293 mm, Clark et al. have documented lower values of 1.05 mm and 0.97 mm. Ning Wen et al. employed a hybrid approach to optimize DLG settings for a True Beam linac [17]**.** Baseline DLG values were measured according to vendor-provided guidelines and similarly optimized in Eclipse [17].

V.CONCLUSION

To ensure accurate dose delivery and prompt detection and correction of discrepancies, the accuracy of the measurement method should be verified by comparison with other independent methods. Ion chamber measurements provide low uncertainty, and a DLG difference of less than 0.2 mm may maintain PTV dose variation within 1% [17]. Thus, we have confirmed that changes in DLG as a function of depth, SSD, dose rate, and photon beam energy do not need consideration in a TPS, despite DLG values being dependent on depth and field size.

More accurate and optimal DLG minimizes uncertainty in dose calculations and provides additional confidence in clinical practice of DLG. More accurate and optimal DLG minimizes uncertainty in dose calculations and provides additional confidence in clinical practice of DLG [22].

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