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Comparative Analysis of MLC Dosimetric Parameters for Varian LINACs: Unique 6X, Clinac iX and TrueBeam at AECH NORI

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Comparative Analysis of MLC Dosimetric Parameters for Varian LINACs: Unique 6X, Clinac iX and TrueBeam at AECH NORI

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Abstract

Purpose: The dosimetric leaf gap (DLG) and transmission factor are two important systematic parameters used to model the rounded MLC leaf end effect when commissioning an Eclipse treatment planning system (TPS). This study investigates the influence of gantry and collimator angles on the dosimetric leaf gap (DLG) and leaf transmission factor (LTF) in three Varian LINAC equipped with rounded end Millennium 120 MLCs. This research also compared the DLG and LTF values for the three LINAC systems. While Varian guidelines recommend DLG measurements at zero degrees for both gantry and collimator angles, this research aims to address the knowledge gap by assessing DLG and LTF variations at different gantry and collimator angles.

Materials and Method: Measurements were performed on the Varian TrueBeam, Clinac iX and Unique 6X LINACs equipped with a Millennium 120 MLC. The beams utilized in this study had energies of 6 MV, 15 MV, 6 FFF. LTF and DLG were determined using PTW Farmer, Semiflex and Pinpoint ionization chambers in water phantoms at gantry angles 0° and 90°. For each gantry angle, measurements were also taken at two collimator angles 0° and 90°. For eight different gantry angle measurements Sun Nuclear stereo phantom (stereoPHAN) was used along with the semiflex chamber. The same methodology was further extended to the Octavius 4D phantom and portal dosimetry to verify the consistency of the results.

Results: Varian specifies that the transmission through its MLCs should not exceed 2% while the DLG is expected to remain below 2mm [8]. The analysis of DLG and LTF values across different Varian linear accelerators demonstrated consistent trends among the investigated chamber types. Chamber wise analysis indicated overall means of 1.30 ± 0.14 mm (Farmer), 1.32 ± 0.16 mm (Semiflex), and 1.36 ± 0.09 mm (PinPoint) for DLG, with corresponding LTF values of 1.35 ± 0.08, 1.41 ± 0.10, and 1.45 ± 0.13. The slightly higher spread observed for Semiflex and PinPoint suggests greater variability compared with Farmer, though all chambers provided clinically acceptable consistency.

Conclusion: This work evaluated dosimetric leaf gap and transmission for three Varian LINACs (TrueBeam, Clinac iX, and Unique 6X) using different ionization chambers, with verification through Octavius 4D phantom and portal dosimetry. TrueBeam yielded the lowest mean DLG (1.22 mm), Clinac iX the highest (1.46 mm), and Unique 6X intermediate (1.41 mm), while transmission factors remained within 1.3% to 1.5% across all machines. Chamber related differences were minor, with PinPoint measuring slightly higher than Farmer and Semiflex.

Overall, the results demonstrate that both machine design and chamber type influence measurements, though the variations remain within clinically acceptable limits for treatment planning accuracy.

1. Introduction

Cancer continues to be one of the most significant global health concerns, with both its incidence and mortality rates increasing despite major medical advancements. The WHO and IARC, classify cancer as a leading cause of death globally, accounting for nearly 10 million deaths in 2020. IARC reported around 20 million new cases in 2022 out of which 9.7 million deaths were recorded [1]. Recent advances in oncology have transformed clinical practice, improving precision in diagnosis, treatment planning and patient outcomes. The transition from traditional methods to highly targeted techniques underscores the crucial role of advanced technologies in clinical practice. Linear accelerators (LINACs) are widely used in modern radiation therapy as the primary machines for delivering high energy x-rays or electrons to treat cancer. These system operate by accelerating electrons through a waveguide using microwave power, which are then directed onto a target to generate therapeutic x-rays. One of the main advantages of LINACs is their ability to produce radiation beams with adjustable energy level and field shapes, allowing treatment to be tailored according to the location, size and depth of the tumor. Over time, LINAC technology has evolved to support advanced techniques such as intensity modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT) and stereotactic body radiotherapy (SBRT) providing greater precision and sparing of healthy tissues [2]. But for the irregular tumor shapes, advancements in the technologies were required and thus MLCs did this job perfectly.

MLCs are the critical component of modern LINACs, designed to shape radiation fields with high precision. It consists of multiple, motor driven tungsten or any other heavy metal leaves that can move independently to conform the treatment beam to the geometry of the tumor. By dynamically adjusting the leaf positions, MLC enabled advanced treatment techniques such as IMRT and VMAT. Despite their precisions, MLCs are not the perfect barriers to radiation. A small amount of leakage still occurs through the completely closed leaf banks [3].

The two MLC parameters have been studied in this experimental research, DLG and LTF that are introduced due to the leaf designs. When the leaves are completely closed, some radiation still gets through because of transmission from edges of the MLC leaves, DLG takes this leakage into consideration and is incorporated into the TPS, since Eclipse algorithm considers the leaves to be rectangular in shape [4]. Along the radiation beam's course, the LTF quantifies the proportion of radiation that penetrates the MLCs. It is determined by calculating the ratio of mean transmission measured through the MLC banks to the dose recorded for a fully open MLC field [4,5].

When integrating the advanced technologies like IMRT/VMAT in the Eclipse TPS (Varian Medical System, Palo Alto, CA), it is necessary to evaluate and verify MLC characteristics. Incorrect modelling of leaf leakage within the TPS may underestimate or overestimate this contribution, leading to the deviations between planned and measured doses. Accurate determination of these parameters is essential for TPS modelling, as errors in LTF and DLG can directly influence calculated dose distributions. Therefore, careful measurement and validation of these factors are necessary to ensure high precision in radiotherapy dose delivery and reduces uncertainties. Different modelling methods are used across various TPS. It is essential to acknowledge that parameters of MLCs differ from machine to machine even if manufactured by the same vendor. For dynamic IMRT QC, various techniques for verifying DLG and LTF have been reported. Lin *et al.* have determine the DLG and LTF value for the Varian TrueBeam using the energies, 6MV, 6 FFF, 10MV and 10 FFF with the single ion chamber at two depths 5cm and 10cm. He also used GAFCHROMIC EBT3 film to check for the DLG and LTF values using the same sliding field method [5]. Shende *et al.* (2017) also measured DLG and LTF value by utilizing the sweeping gap methodology for Varian TrueBeam for 6MV, 10MV, 15MV, 6FFF and 10FFF. He used 0.13cc semiflex chamber and 2D array matrix as detector [6]. Rostami *et al.* (2024) measured DLG and LTF values using solid water hantom at different angles to check for the effects of gravity on the MLCs motion using the sweeping gap methodology [7].

The DLG is not only an important parameter needed for TPS, but is also directly correlated with effective leaf gaps. Tracking DLG variations can directly verify leaf gap consistency. The DLG can be derived from a set of measurements of sweeping fields of different gap widths using a single detector typically an ion chamber. In this paper, we investigated the measurement of DLG in three LINACs using different detectors and look for the variations of the results obtained. We also determine DLG at different gantry angles to assess the gravity effects on the MLCs. The validation test was also performed for the obtained results.

2. Materials and Methods

2.1 LINACs: This work involves three LINAC models manufactured by Varian Medical System: Unique 6X, Clinac iX and TrueBeam. All LINACs are equipped with Millennium 120 MLCs. Typically Varian MLCs have 120 independent tungsten leaves. These are divided into two banks, sixty on each side. Each bank is sub-divided into two portions according to the thickness. The forty periphery MLCs have thickness of 1cm and inner 20 leaves are narrower with the thickness of 0.5cm.

2.2 Detectors: Different ionization chambers were used to evaluate the effect of detector size on DLG measurements. A PTW 0.6 cc Farmer chamber (30013), calibrated at PINSTECH while PTW 0.125 cc Semiflex chamber (31010) were cross calibrated on-site providing reliable performance across a wide range of fields. For high-resolution measurements in small fields, a PTW 0.016 cc PinPoint chamber was also included, calibrated on-site.

Portal dosimtery was performed with the amorphous silicon a-Si 1200 and a-Si 1000 EPID for TrueBeam and Clinac iX respectively. These instruments were selected for their ability to provide both precise readings and high-resolution dose information, particularly important for complex treatment fields.

The Octavius 4D phantom equipped with the PTW 1500 detector array was employed for independent verification. The detector consists of 1405 vented ionization chambers arranged in a matrix configuration with center-to-center spacing of the ion chambers of 7.1 mm and dimensions of 4.4 mm x 4.4 mm x 3 mm, providing high spatial resolution and uniform coverage of the measurement plane. Its design enables time-resolved, three-dimensional dose reconstruction by synchronizing with gantry rotation, making it particularly suitable for dynamic techniques such as IMRT and VMAT.

2.3 Phantoms: Sun nuclear Stereophantom in conjunction with semiflex chamber was specifically used for the measurement of DLG values for eight different gantry angles. PTW 1-D water phantom was used for one dimensional measurements and single gantry angle that is 90°. Data obtained from the different detectors was systematically compared across the three LINAC systems. Particular attention was given to the determination of accurate MLC modelling parameters, including DLG and interleaf leakage, within the TPS.

3. Measurement of DLG and LTF value

The DLG values were calculated following the sweeping gap methodology described by Rostami *et al.* and Lin *et al.* [5, 7] but using different detectors on the three LINACs. In this method, opposing MLC leaf banks are set to traverse the radiation field of 12 x 12 cm^2 while maintaining a constant opening between them. During the sweep, a detector measures the charge for different gap widths. For each gap measurement including 2, 4, 6, 10, 14, 16, 20 mm, there is a corresponding response R recorded at electrometer which was then manipulated according to Varian's recommendation. This technique effectively accounts for the transmission characteristics and geometric influence of rounded leaf ends and is widely adopted for

commissioning and quality assurance of TPS. The average of the transmissions through bank A ($R_{T,A}$) and bank B ($R_{T,B}$) is calculated as;

$$\boldsymbol{R_T = \frac{R_{T,A}+R_{T,B}}{2}} \qquad \textbf{(1-1)}$$

The average of MLC transmission to the gap reading R_{gT} for each gap reading was calculated using the equation 1-2.

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

Here the g[mm] the gap width while the 120[mm] is the movement range of the sweeping gap. To look for the ionization contributed due to sweeping gap fields, the transmission through the MLC should be subtracted because the chamber was completely shielded by the leaves. Corrected gap reading of ionization for each gap reading was defined as; $\boldsymbol{\dot{R}_g = R_g - R_{gT}}$ which is then plotted against gap measurements [5]. R_g is the initial sweeping gap field response. The plot should follow the linear trend to calculate the y-intercept 'c' and absolute value of that intercept gives the DLG measurement. Leaf transmission factor was calculated using $\boldsymbol{LTF = R_T/R_{open}}$

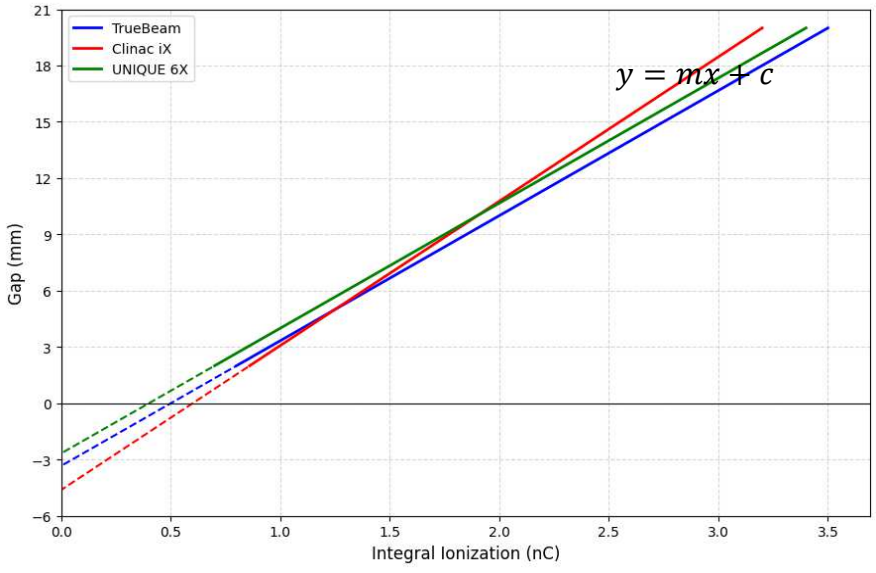


Figure 3-1 Gap vs Ionization ($\dot{R}_g$)

The chamber depth in the phantom was maintained at 10 cm with source-to-surface distance (SSD) of 100 cm [4]. However, an extended SSD of 140 cm is usually used when

utilizing the 6 MV flattening filter free (FFF) beam for EPID as depicted in figure 2-2. This modification is required because FFF beams have a greater dose rate, which might cause detector saturation.



Figure 3-2 Portal Dosimetry

The study was carried out at two gantry angles 0° and 90° with collimator angles 0° and 90° applied independently, in order to evaluate and compare the transmission characteristics of the three LINAC system. The two collimator angles were specifically investigated to assess their influence in the calculated DLG values. This variation arises from the orientation of the ion chamber relative to the incident radiation beam. In one configuration, the chamber is placed parallel to the beam and is irradiated simultaneously while in the other, the chamber is perpendicular and receivers radiation gradually as the MLC gap sweeps across. In accordance with the Varian's recommendations, the results obtained at different collimator angles were averaged for consistency. Measurements at gantry angle 0° were carried out with a one-dimensional (1-D) water phantom, while 90° measurements were performed using the MP3 three dimensional water phantom to evaluate dose distribution.



Figure 3-3 1-D Water Phantom Setup at TrueBeam

In addition measurements were repeated for the same $12 \times 12\ cm^2$ field size for eight different gantry angles including 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° for two photon energies 6 MV and 6 FFF. This was done to evaluate the potential impact of gantry rotation on MLC transmission. The use of Sun Nuclear StereoPHAN allowed measurements at different gantry angles and provides stable positioning and reproducibility while minimizing the errors, also shown in the figure below. Semiflex ionization chamber was specifically used with stereoPHAN because it offers an optimal balance between volume and sensitivity and its moderate volume reduces the over volume-averaging.



Figure 3-4 StereoPHAN Setup at TrueBeam

4. Results

All the Varian LINACs used in this study (TrueBeam, Clinac iX and Unique 6X) are equipped with Millennium 120 MLC system and each have its unique DLG and LTF parameters that are incorporated into the TPS against each energy and LINAC. It is important to admit that LINACs have slightly different parameters even for the same model and manufacturer.

4.1 Results using ionization chambers

The assessment of the obtained data with ionization chambers employed with water phantoms (table 4.1) indicates that TrueBeam being the advanced LINAC shows least inter leaf leakage for the three ionization chambers. The other LINACs have slightly higher value but remain within 2% for DLG and <2% for transmission. 1.32 mm and 1.6% for 15 MV energy, 1.22 mm and 1.5% for 6 MV, 1.14 mm and 1.3% for 6 FFF with Semiflex chamber on TrueBeam was incorporated into the TPS system, so while planning the dose distribution, Eclipse system accounts for this DLG value.

Table 4.1 DLG and LTF values using ionization chambers

Detectors		TrueBeam						Clinac iX				Unique 6X	
		15 MV		6 MV		6 FFF		15 MV		6 MV		6 MV	
		DLG (mm)	LTF %	DLG (mm)	LTF %	DLG (mm)	LTF %	DLG (mm)	LTF %	DLG (mm)	LTF %	DLG (mm)	LTF %
Farmer	G_0	1.33	1.6	1.19	1.4	1.12	1.4	1.52	1.5	1.39	1.3	1.40	1.3
	G_{90}	1.33	1.7	1.17	1.5	1.00	1.3	1.70	1.4	1.38	1.4	1.43	1.4
Semi Flex	G_0	1.32	1.6	1.22	1.5	1.14	1.3	1.49	1.5	1.42	1.3	1.41	1.3
	G_{90}	1.28	1.7	1.16	1.5	1.01	1.3	1.63	1.6	1.52	1.5	1.45	1.4
Pin Point	G_0	1.31	1.6	1.15	1.4	1.20	1.3	1.52	1.5	1.34	1.4	1.39	1.3
	G_{90}	1.33	1.7	1.11	1.5	1.11	1.3	1.55	1.5	1.38	1.4	1.65	1.2

The comparative graph in figure 4-1 represents the results obtained from three ionization chamber measurements across three different linear accelerators for 6 MV at gantry angle 0°. Overall, the detectors show good consistency, though slight variations are observed depending on the machine and active volumes of chambers.

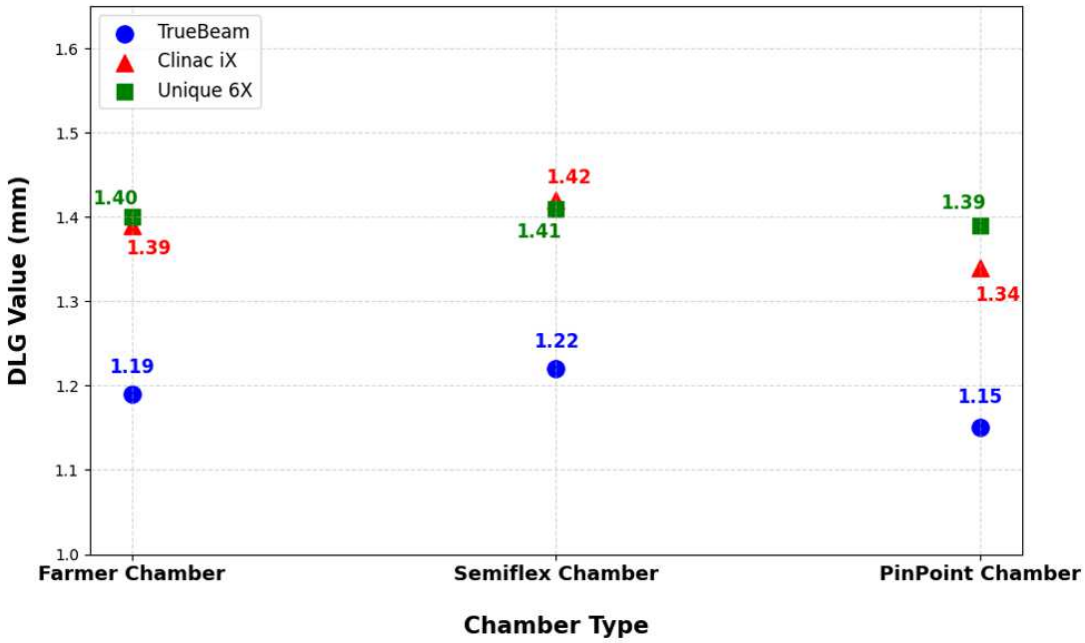


Figure 4-1 DLG values for gantry angle 0° and 6 MV energy

The graph in figure 4-2 presents the comparison of dosimetric parameters measured for the three LINAC systems, showing the variations in DLG and leaf transmission when assessed with three different ionization chambers for 15 MV energy.

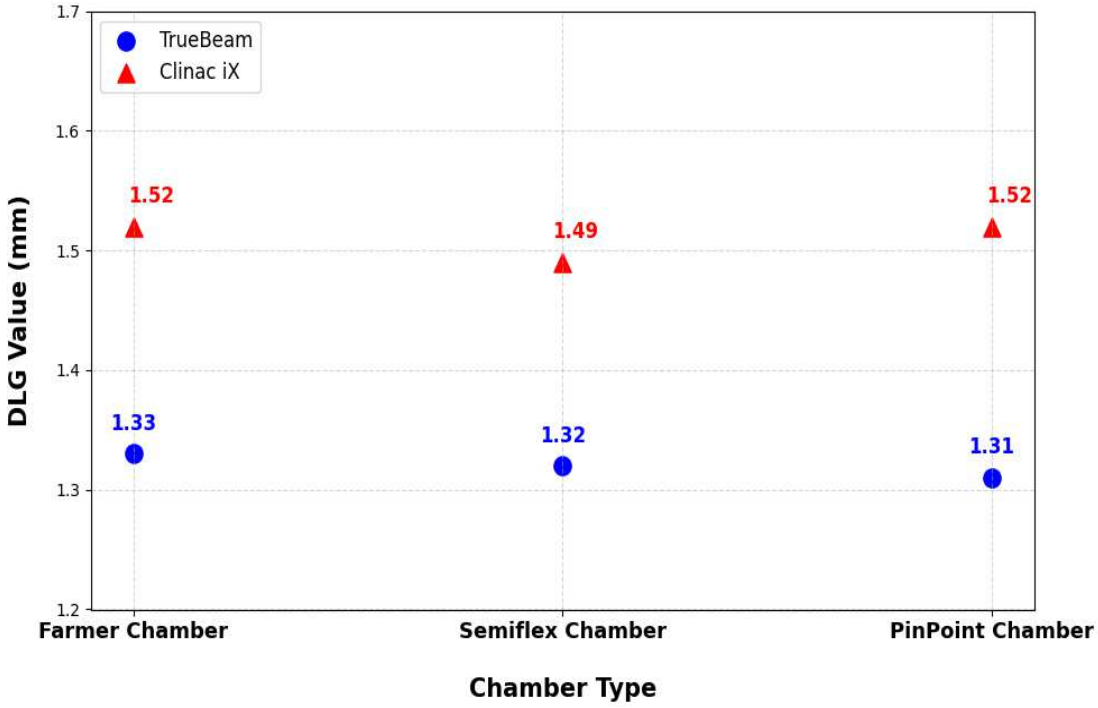


Figure 4-2 DLG values for gantry angle 0° and 15 MV energy

4.1 Results from EPID

EPID a-Si 1200 and a-Si 1000 were used for TrueBeam and Clinac iX models for portal dosimetry. The EPID demonstrated consistency and effectiveness in the measurement of both parameters, with the aid of compatible and clear results that help in analysing the responses of the MLC system on the Varian LINAC. The detail of the DLG and LTF values for different machines and energies are mentioned in the table 4.2.

Table 4.2 DLG and LTF values for different LINACs using EPID

	TrueBeam						Clinac iX			
	6 MV		15 MV		6 FFF		6 MV		15 MV	
	DLG (mm)	LTF (%)	DLG (mm)	LTF (%)	DLG (mm)	LTF (%)	DLG (mm)	LTF (%)	DLG (mm)	LTF (%)
G_0	1.03	1.2	1.41	1.6	1.02	1.7	1.2	1.1	1.27	1.6

4.2 Results from Octavius Phantom

Even when point dose and portal based measurements are available, the Octavius 4D phantom remains indispensable for validating volumetric dose delivery and strengthening the reliability of advanced radiotherapy quality assurance. The results obtained from Octavius 4D are shown in the table 4.3

Table 4.3 Results obtained from TrueBeam using Octavius 4D Phantom

	TrueBeam					
	6 MV		15 MV		6 FFF	
	DLG (mm)	LTF (%)	DLG (mm)	LTF (%)	DLG (mm)	LTF (%)
G_0	1.29	1.6	1.26	1.7	1.09	1.4

The graph in figure 4-3 illustrates the comparison of dosimetric parameters for the studied LINAC system, highlighting variations in DLG and leaf transmission measured with different energies.

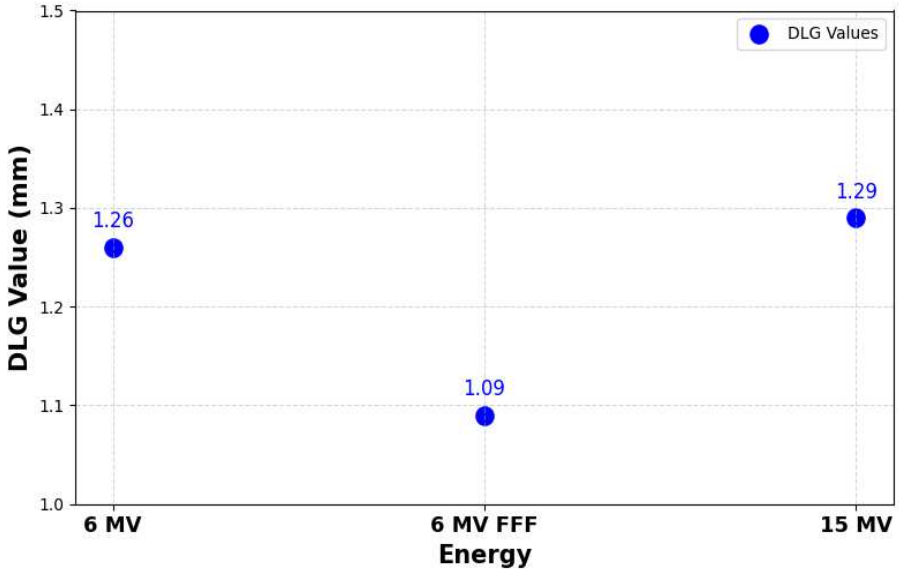


Figure 4-3 DLG values using Octavius 4D phantom at gantry angle 0°

4.3 DLG values at different gantry angles

For 6 MV photon beam, the measured DLG absolute values were 1.47, 1.45, 1.52, 1.53, 1.54, 1.45, 1.37 and 1.38 mm for G_0, G_{45}, G_{90}, G_{135}, G_{180}, G_{225}, G_{270} and G_{315} respectively with the collimator angle 0°. For 6 FFF photon beam, the measured DLG absolute values were 1.00, 1.06, 1.05, 1.08, 1.04, 1.01, 0.98 and 0.99 mm for G_0, G_{45}, G_{90}, G_{135}, G_{180}, G_{225}, G_{270} and G_{315} respectively with the collimator angle 0°. These results shows that DLG value is slightly higher for gantry angle 90° than gantry angle 270°. Measurement was performed with Sun nuclear stereoPHAN by inserting the 0.125cc semiflex ionization chamber in the insertion. The evaluation of the data clearly shows that the DLG values vary with changing gantry angles as shown in figure 4-4.

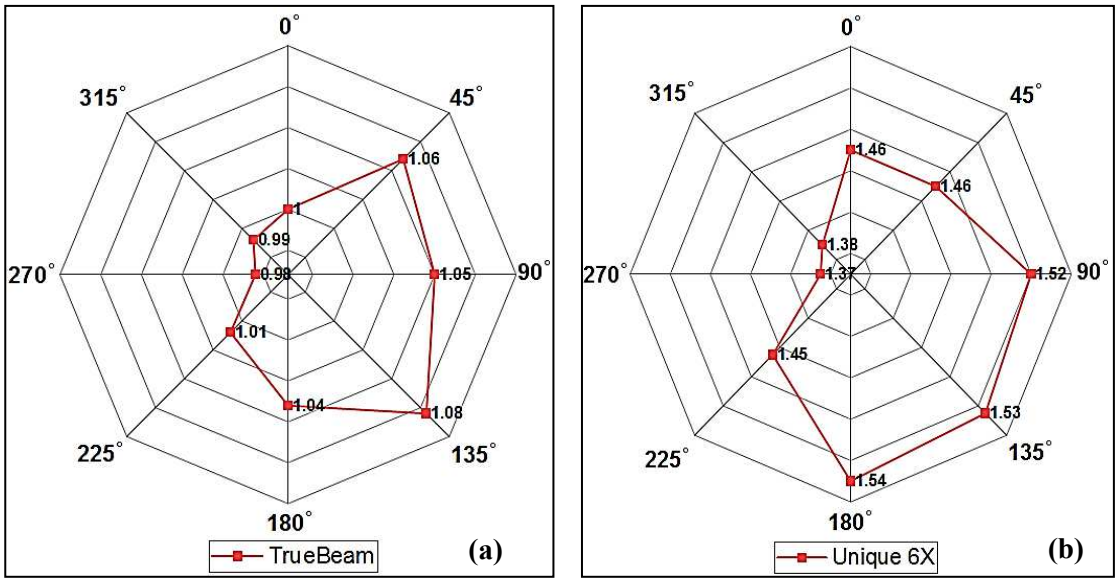


Figure 4-4 Effect of gantry angles on DLG value (a) 6 FFF (b) 6 MV

5. Validation of DLG and LTF

In this study, the distance to agreement (DTA) test was used as part of the verification process for DLG values calculated for three Varian linear accelerators: Unique 6X, Clinac iX and TrueBeam. The measured DLG values for were in line with accepted clinical norms and available literature, suggesting that the dose estimations were correct and is reported by Chih-Yuan Lin *et al.* and Aram Rostami *et al.* [5, 7]. We compared the DLG values, shown in table 3.5, by performing a gamma pass rate study to validate the DLG value.

To evaluate the accuracy of MLC modelling and the applied DLG values, three standardized Varian verification plans named as Aida, Dynamic Chair, and Flat Fluence were selected. These plans are specifically designed to test the performance of the treatment delivery systems. Each plan was delivered on the EPID a-Si1200, which served as the measurement device, and the acquired data were subsequently analysed using the Eclipse v16.1 treatment planning system. The gamma index method was employed for the evaluation, with acceptance criteria set at 3%/3 mm and 2%/2 mm, while the dose threshold was fixed at 10% to exclude low-dose regions that are not clinically significant.

For consistency, reference values were taken from the PTW Semiflex ionization chamber, as this detector was used during the original commissioning of the LINAC. The applied DLG values for plan validation were 1.22 mm for 6 MV, 1.32 mm for 15 MV, and 1.14 mm for 6 FFF,

corresponding to the measured chamber data. These values ensured that the TPS calculations reflected the detector-based reference for each beam quality.

In the evaluation, both the Aida and Flat Fluence plans passed the acceptance criteria for all beam energies. However, the Dynamic Chair plan at 15 MV failed to meet the gamma pass rate, indicating a discrepancy between measurement and calculation. This deviation, however, is not clinically concerning, as the 15 MV energy is not representative of routine clinical practice in IMRT or VMAT. The lack of clinical relevance of this test plan explains the observed discrepancy and confirms that it does not undermine patient treatment quality or the validity of the study outcomes. Overall, the analysis supports the robustness of the validated DLG values and demonstrates that the EPID based verification method provides reliable agreement for clinically implemented treatment plans.

Table 5.1 Distance to Agreement Test

Energy	DLG (mm)	Plan name	3%/3 mm	2%/2 mm
6 MV	1.22	Aida	99.9%	95.2%
		Flat Fluence	99.8%	98.0%
		Dynamic Chair	99.9%	96.2%
15 MV	1.32	Aida	100%	96.7%
		Flat Fluence	99.8%	97.9%
		Dynamic Chair	87.7%	77.6%
6 FFF	1.14	Aida	100%	99%
		Flat Fluence	98.2%	96.5%
		Dynamic Chair	96%	93%

6. Discussion

This study investigated the dosimetric performance of MLCs by assessing the DLG and LTF across three Varian LINAC platforms, Unique 6X, Clinac iX, and TrueBeam. Measurements were performed using ionization chambers, EPID and the Octavius 4D phantom. Overall, the results showed consistent MLC behaviour across the systems, with small variations largely attributed to the characteristics of the detectors and the technical configuration of each machine. The DLG

values obtained in this work fall within the range reported in previous studies for Varian MLCs, typically 1-2 mm depending on model type and measurement approach. Rostami *et al.* demonstrated that DLG varies between Millennium 120 MLCs of different LINACs, which supports our finding of slightly smaller DLG values in the TrueBeam MLC relative to the Clinac iX and Unique 6X. Similarly, our measured leaf transmission factors were consistent with the published range of approximately 1-2% reflecting the stable transmission performance of Varian MLCs and highlighting incremental improvements in more recent systems.

Results from ionization chambers measurements demonstrate agreement, with only slight differences linked to the inherent response of each detector type. The observed trend indicates stable and consistent MLC performance across all machines, while also reflecting the ability of the detectors to capture subtle variations in beam modulation. These findings confirm the robustness of the experimental approach and reinforce the accuracy of TPS modelling.

We see that ionization chambers yields a bit larger DLG value as compared to the EPID and this observation is in good agreement with the Motiur *et al.* [8]. This discrepancy is expected, as chambers provide water-equivalent absolute dose measurements based on rigorous calibration protocols. Ionization chambers measure the charge from photon interactions in a defined gas volume, offering stable, water-equivalent response and thus serving as the reference standard in dosimetry. Also, it does not affect the off- axis dose at the large distance because it accounts only for central axis dose [6]. EPIDs, however, rely on amorphous silicon panels with higher atomic number materials, which alters their energy absorption properties, particularly for scattered or low-energy photons, leading to lower reported doses. Their placement downstream in the LINAC head further introduces scattering and attenuation effects. EPIDs are optimized for relative fluence detection and are influenced by energy dependence, backscatter within the panel and inhomogeneity characteristics of the photon fluence. Unlike ion chambers, which are calibrated under reference conditions to measure dose in water, EPIDs are designed primarily for imaging and relative dose verification. The amorphous silicon panels used in EPIDs are not water-equivalent, leading to differences in energy absorption and reduced sensitivity to low-energy and scattered photons [9].

The Octavius 4D phantom, on the other hand, produced planar dose measurements closely matching chamber data, consistent with the reported values in this research which confirmed its reliability in capturing three dimensional dose distributions under dynamic treatment conditions. The Octavius 4D phantom provides a sophisticated solution for patient-specific quality assurance by enabling dynamic verification of delivered dose distributions. While

ionization chambers are considered the standard for precise absolute point dose measurements, they are restricted to single locations and cannot account for spatial variations. Portal dosimetry, on the other hand, offers two-dimensional fluence information but does not fully capture the three-dimensional dose distribution within patient-equivalent geometry. The Octavius 4D system overcomes these limitations through a detector array that rotates in synchrony with the treatment gantry, allowing reconstruction of the dose in three dimensions with both high spatial and temporal accuracy [11].

MLC transmission was found larger with flattened beams than FFF beams in TrueBeam which aligns with the Shende *et al.* and the reason behind is attributed to the shape of the flattening filters which has an impact on the FFF energies. Absence of filters soften the beam which results in the lowering of DLG and LTF values. Also, FFF beams are more forward directed at the peak than at the lateral sides [6].

The DLG values were found to be different for three types of LINACs installed, suggesting that machine type affects the leakage between the banks of MLCs during MLC motion, most likely as a result of variations in leaf design and calibration. The Millennium MLCs on Unique 6X and Clinac iX with rounded leaf ends, exhibit slightly larger effective gaps due to increased penumbra and partial transmission at narrow openings. TrueBeam's MLC, designed with finer leaf resolution and improved mechanical accuracy, minimizes these effects and yields smaller DLG values, although they are manufactured by the same Varian company. The measured transmission is governed by photon penetration through tungsten leaves; while leaf thickness and design minimize this, minor differences remain due to design tolerances and interleaf leakage. Our research also shows that the DLG value varies with the gantry angle. The DLG values were found to be large at gantry angle 90° and small at gantry angle 0° for 6 MV and 6 FFF energies. This is due to the gravity effects on the MLC movement at different gantry angles [4]. These results are in line with earlier research that shows advancements in MLC design and control systems in more recent Varian LINACs [4, 5, 6, 7].

Accurate characterization of DLG and LTF is critical for TPS commissioning, as these parameters directly affect MLC sequencing in IMRT and VMAT. Inaccurate estimation of DLG can introduce systematic errors, particularly in high modulation fields with small apertures, while incorrect LTF modelling may underestimate leakage doses, impacting normal tissue sparing. The good agreement among chambers, EPID, and Octavius in this study highlights the robustness of the methodology and supports the accuracy of MLC modelling within the TPS for all three LINACs. The assessment of the obtained results indicates that TrueBeam shows least inter leaf

leakage. This implies that for the more confined and small tumors, where conformal dose distribution is required TrueBeam should be prioritize.

7. Conclusion

Across all machines, the results follow a consistent pattern, with minor deviations attributed to the response characteristics of each detector. This agreement confirms the validity of the measurement technique and demonstrates the robustness of MLC modelling within the TPS. These results highlight how crucial it is to account for mechanical aspects in MLC modelling and treatment planning. Variations in DLG can have a direct effect on beam modulation and dose estimations, which can compromise patient safety and treatment effectiveness. Therefore, for accurate and dependable radiation treatment delivery, it is essential to comprehend and mitigate the effects of gravity-induced mechanical distortions on DLG. Despite Varian standards that recommend DLG measurements at G_0 and G_{90} degrees only, our work shows that DLG varies with gantry angle in gantry angle. As stated in our technique, we recommend using an averaged DLG value from measurements made across several gantry angles because Eclipse TPS only accepts one value for DLG per energy.

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