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(Research Article)

Beam profile characteristics of a Varian linear accelerator across different photon energy levels

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Abstract

Radiotherapy employs variety of energy radiation to destroy cancer cells. A linear accelerator(also called LINAC) is the machine used to delivered external beam radiation therapy.In order to confirm the treatment planning systems that deliver the best radiation to the tumors while sparing the surrounding normal tissues, extensive measurements of dosimetric parameters are part of the commissioning procedure of a LINAC for clinical usage. This work aimed to compare and assess photon beam profiles with respect to penumbra width, symmetry, and beam flatness. Beam profile measurements were performed for this study atTMSS Cancer Center, Bogura, Bangladesh, using a linear accelerator (Varian VitalBeam SN: 5199) with 6MV,10MV and 15MV photon energies for a set of field sizes (4 × 4, 10 × 10 and 20 × 20 cm^2) and various reference depths keeping the same environmental conditions. A 3D water phantom, CC13 ionization chamber (SN:18635)as a reference chamber, CC04 ionization field chamber (SN:18616) as a and IBA myQA Accept software version 1.6 were used to measure the profiles of photon energies 6 MV, 10 MV 15 MV respectively. Utilizing the Eclipse (Version: 16.1) external treatment planning system, the profile calculation was carried out. According to the manufacturer's and IEC specifications, the photon beam profile data from the current investigation are compatible, and all of the tolerances fall within the ranges of clinically acceptable tolerance.

Keywords: Beam Profile; Symmetry; Flatness; Penumbra Width; LINAC etc

1. Introduction

Radiation therapy aims to preserve the surrounding healthy tissues while administering the highest dose possible to the tumor (target) region. With the help of a linear accelerator (LINAC), high energy beams can be tailored to fit the exact geometry of a tumor, eliminating cancer cells while sparing the surrounding healthy cells. In order to accomplish this, the medical physicist makes quality control measurements along the entire process to guarantee that the system is functioning as intended [1].It is crucial that the data gathered are as accurate as possible to prevent dosimetric and patient treatment errors because treatment planning systems use the commissioning of a LINAC data as reference data [2].

One of the most important aspects of commissioning is the beam profile measurements, which are required before a LINAC is used therapeutically. A beam profile is the graphical representation of the relative dose versus the distance from the central axis at a specific depth. Three parameters that quantify the beam profile uniformity are determined as beam symmetry, beam flatting, and penumbra width.

In this study, the beam profile measurements were performed for 6MV, 10MV and 15MV photon energies for a set of field sizes (4 × 4, 10 × 10 and 20 × 20 cm^2) and various specific depths. The Varian VitalBeam linear accelerator

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equipment was used for these measurements, which were carried out in a 3D computer-controlled water phantom (Smart Scan) atTMSS Cancer Center, Bogura, Bangladesh.

2. Material and methods

2.1. Instrumentation

This study used a Varian VitalBeam linear accelerator (SN: 5199), which has a dual energy mode and the ability to handle both photon and electron beams. It has four photon energies (e.g., 6 MV, 10 MV, 15 MV, and 6 FFF MV) and five electron energies (e.g., 4 MeV, 9 MeV, 12 MeV, 15 MeV, and 18 MeV). The beam profile for photon energies of 6 MV, 10 MV, and 15 MV was measured using a 3D water phantom, CC13 ionization chamber (SN:18616) as a field chamber, CC04 ionization chamber (SN:18635) as a reference chamber and IBA myQA Accept software version 1.6. The beam profile computation was performed using the Eclipse (Version: 16.1) external treatment planning system.

2.2. Beam Profile Measurement

The dose change obtained at a certain depth along the vertical line of the centerline axis is called the beam profile. The beam profile includes symmetry, flatness and penumbra width [3].

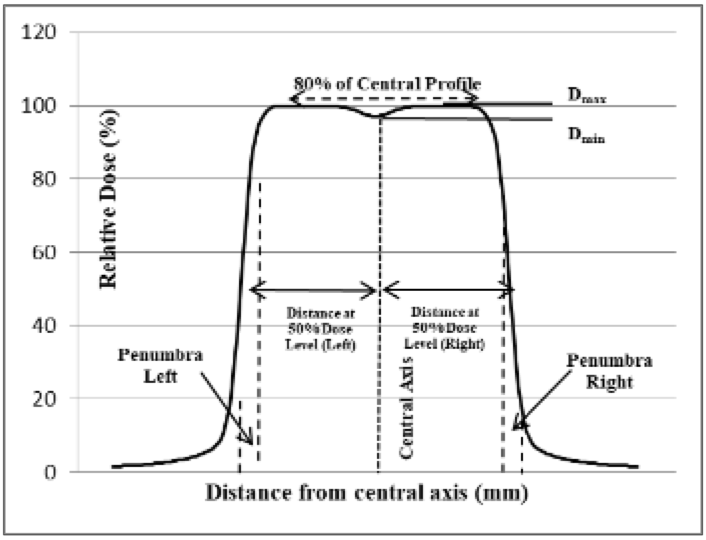

Figure 1 The measurements of beam profile

The beam symmetry is defined as the difference between the left and right distances of dose points on a beam profile from the central axis point at 50% dose level. Symmetry is then calculated from

$$\text{Symmetry} = \frac{\text{Distance}_{\text{Left}} - \text{Distance}_{\text{Right}}}{\text{Distance}_{\text{Left}} + \text{Distance}_{\text{Right}}} \times 100\%$$

The dose should not differ more than 2% at any pair of points situated symmetrically with respect to the central ray.The flatness for photon beams is traditionally defined as the transverse variation of dose relative to the central axis over the central 80% of the beam width of the beam profile at 10 cm depth in a plane perpendicular to the central axis [4]. Flatness is then determined from

$$\text{Flatness} = \frac{\text{D}_{\text{max}} - \text{D}_{\text{min}}}{\text{D}_{\text{max}} + \text{D}_{\text{min}}} \times 100\%$$

Where, $D_{max}$and $D_{min}$are the maximum and minimum dose values in the central 80% of the central profile respectively. The acceptance dose variance is 3% for a 10x10cm^2 field size, 100 cm source to surface distance (SSD) and 10 cm depth. The photon penumbra is typically defined as the distance between the 80% and 20% dose points on a transverse beam profile measured in a water phantom.

2.3. Experimental Procedure

To measure beam profile a 3D water phantom and a CC13 ionization chamber (SN:18616) were set at isocentre alignment of the LINAC system. The 3D water phantom was leveled with spirit level and the source to water surface distance was set at 100 cm.A CC04 reference chamber (SN:18635) was set in the corner of the measuring field just above the water surface. The beam profiles scanning was performed for 6 MV, 10 MV and 15 MV photon beams with various field sizes and reference depths. Scanning was controlled by IBA MyQA Accept software version 1.6.

The beam profile curves were acquired for three field sizes (4 × 4, 10 × 10 and 20 × 20 cm^2) at various reference depths. For 6 MV, 10 MV and 15 MV photon beams, the specific depths were set (1.6, 5.0, 10.0, 20.0 and 30.0) cm, (2.4, 5.0, 10.0, 20.0 and 30.0) cm, and (2.9, 5.0, 10.0, 20.0 and 30.0) cm respectively. The curves were smoothed in Eclipse software (Version: 16.1, Algorithm: AAA and PO). Finally, the calculation and plotting the graph of this work was performed using MS Excel software.

3. Results and discussion

Profile dose measurements were performed for field sizes (4 × 4, 10 × 10 and 20 × 20 cm^2)and various depth variations for 6 MV, 10 MV and 15 MV photon energies. The profile dose curves were obtained for photon energies 6MV, 10MV and 15MV and each of the field sizesare displayed in Figure-2 to Figure-10. The measured values of symmetry, flatness and penumbra width for various specific depths and photon energies (6MV, 10 MV and 15 MV) are presented in Table-1 to Table-3.

Our research founds that, the range values of beam symmetries for 6 MV, 10 MV and 15 MV photon energies are (0.03-0.28) %, (0.01-0.25) % and (0.01-0.30) % respectively [6,10]. As the penetrating power of the photon beam decreases with increasing depth, the beam flatness increases with increasing depth due to the presence of different energy photons in the same energy beam. Beam flatness increases with increasing field size because photon beam dispersion increases with increasing field size and the same beam is composed of photons with different energy values. We also noticed that, beam flatness increases with increasing beam energy. As the energy difference between the photons located in the same beam increases, flatness increases with beam energy. The value of beam flatness estimated in this study at 10 cm depth with field size 10x10 cm^2 and SSD 100 cm are 2.51%, 2.62% and 2.90% for 6 MV, 10 MV and 15 MV photon energies respectively. As the obliquity of the photon beam at the edges of the blocks at collimator openings increase with field size and beam energy, the penumbra increases with the increase of field size and beam energy respectively. Because of dispersion increases with the increase of distance photon beam travels, penumbra increases with increase of depth. The range values of penumbra width are (0.51-1.30) cm, (0.58-1.37) cm and (0.62-1.42)cm respectively for 6 MV, 10 MV and 15 MV photon energies[8]. The penumbra values for field size 20 x 20 cm^2 with 30 cm depth are just outside the recommended limit of 1.2 cm. The increased rate of beam flatness and penumbra width with the increase of field size, depth and beam energy do not have linear relationship because the modes of interaction of beams with matter are vary with different parameters.

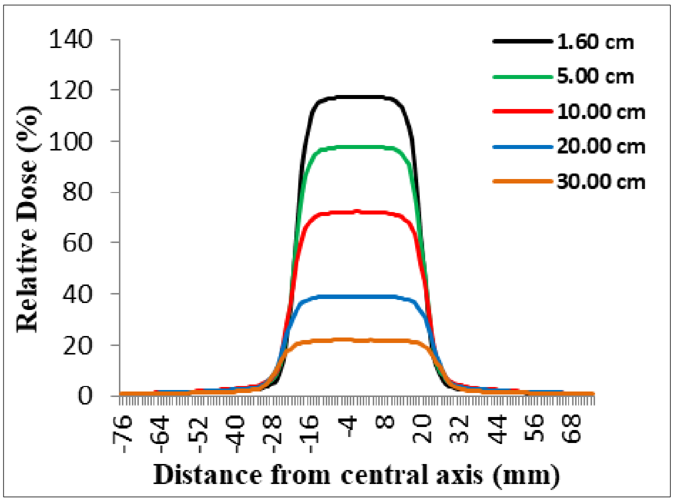

Figure 2 Profile doses curve of 6 MV photon for FS 4x4 cm^2 with various depth

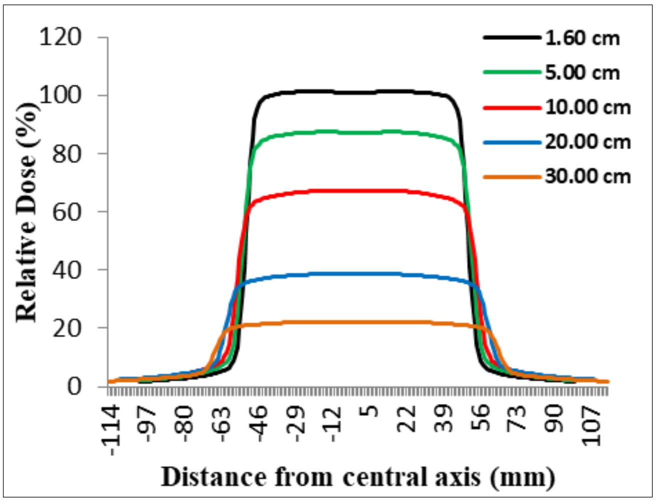

Figure 3 Profile doses curve of 6 MV photon for FS 10x10 cm^2 with various depth

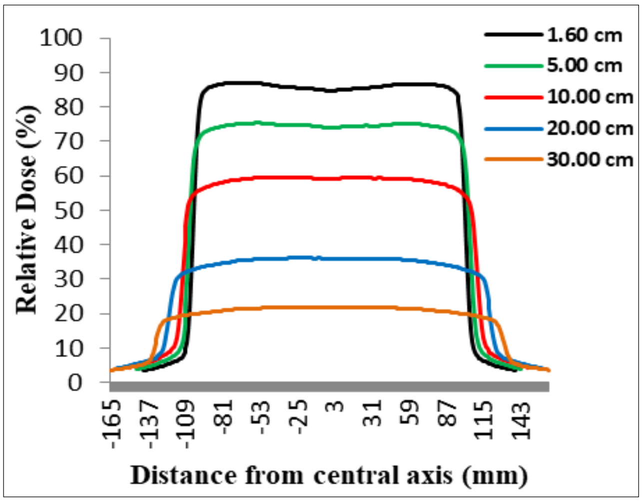

Figure 4 Profile doses curve of 6 MV photon for FS 20x20 cm^2 with various depth

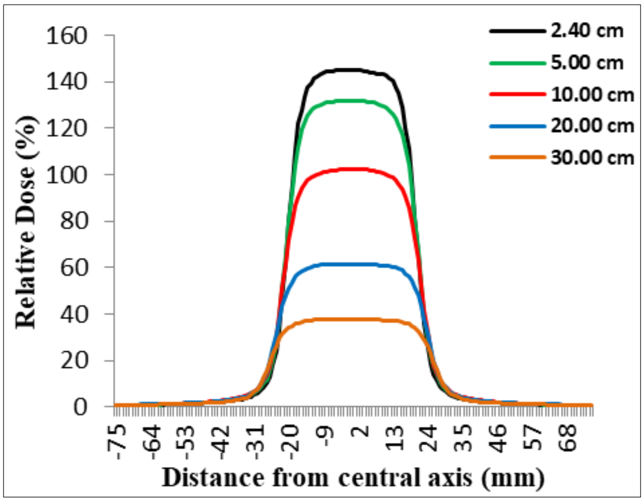

Figure 5 Profile doses curve of 10 MV photon for FS 4x4 cm^2 with various depth

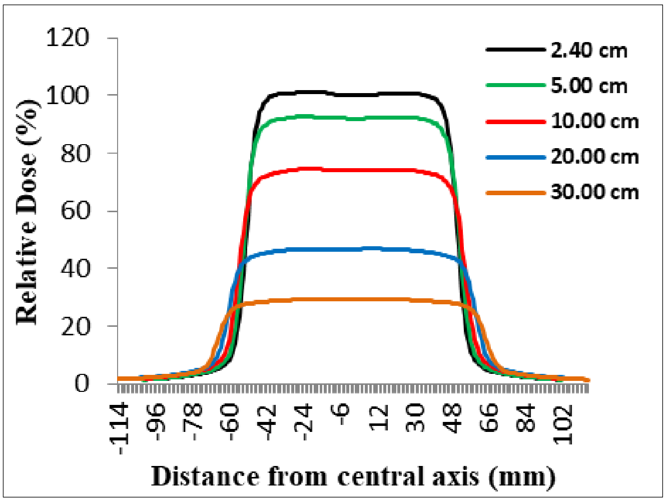

Figure 6 Profile doses curve of 10 MV photon for FS 10x10 cm^2 with various depth

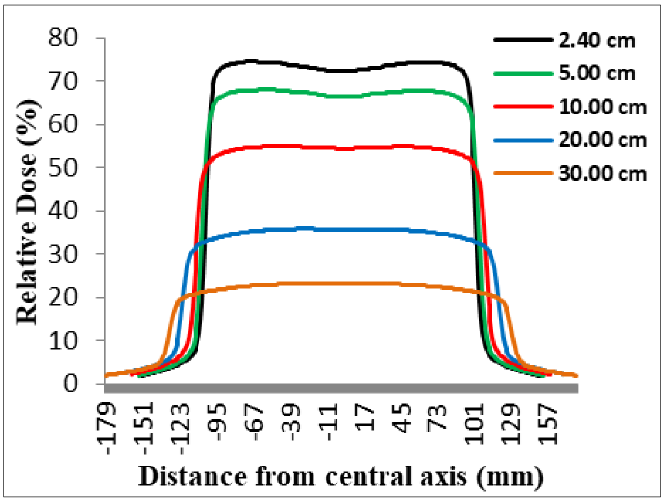

Figure 7 Profile doses curve of 10 MV photon for FS 20x20 cm^2 with various depth

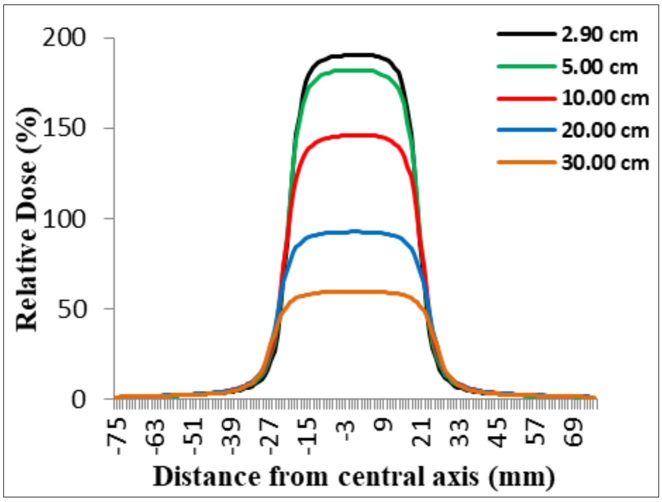

Figure 8 Profile doses curve of 15 MV photon for FS 4x4 cm^2 with various depth

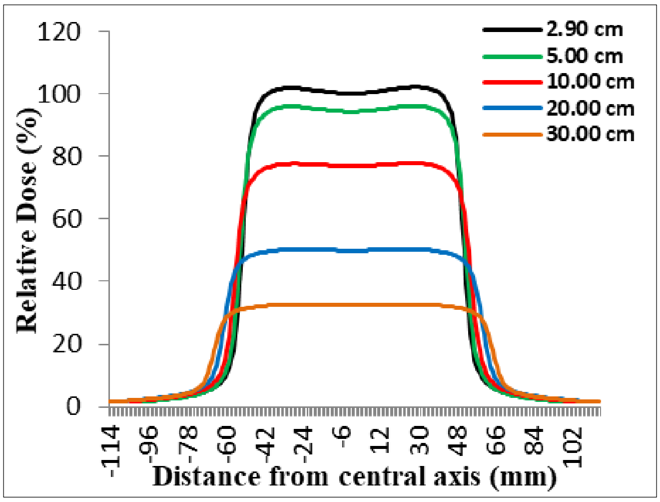

Figure 9 Profile doses curve of 15 MV photon for FS 10x10 cm^2 with various depth

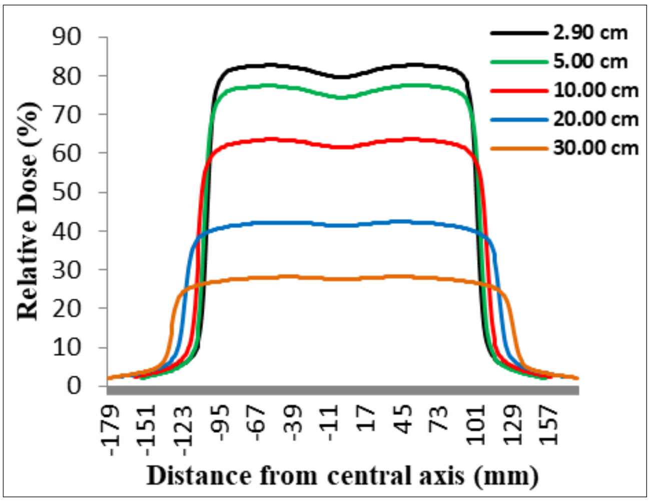

Figure 10 Profile doses curve of 15 MV photon for FS 20x20 cm2 with various depth

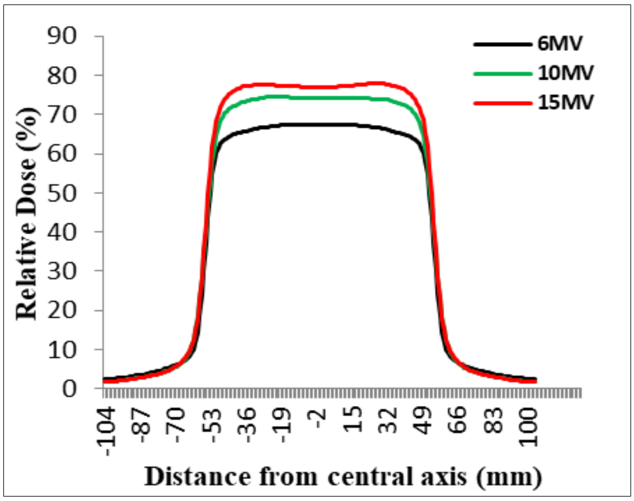

Figure 11 Profile doses curve of various photon for FS 10x10 cm^2 with 10 cm depth

The beam profile data and corresponding profile curves for various photon energies at 10 cm depth and 10 x10 cm^{2}field size are presented in Table-4 and displayed in Figure-11 respectively [7]. Beam profile data with field size variation for various photon energies are presented in Table-5 to Table-7. The variation curves of beam flatness and penumbra width with depth, field size and energy are displayed in Figure-12 to Figure-15 [9].

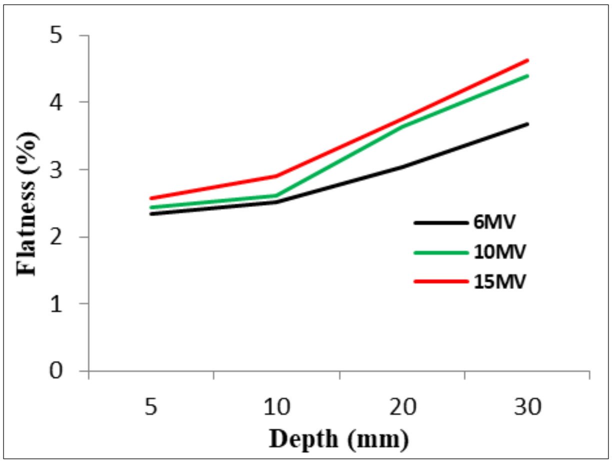

Figure 12 Variation of flatness with depth for various photon beams with FS 10x10 cm^2

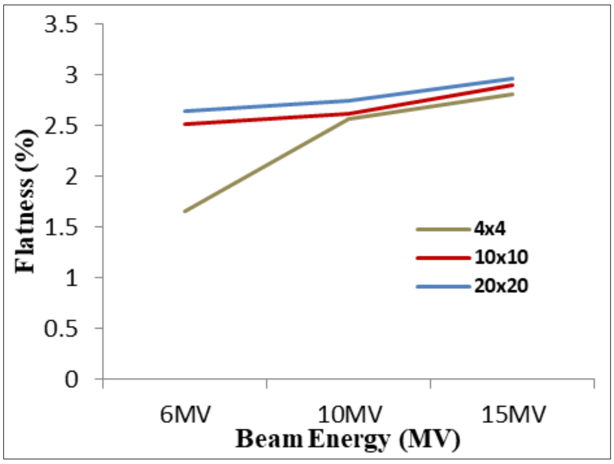

Figure 13 Variation of flatness with FS for various photon beam at 10 cm depth

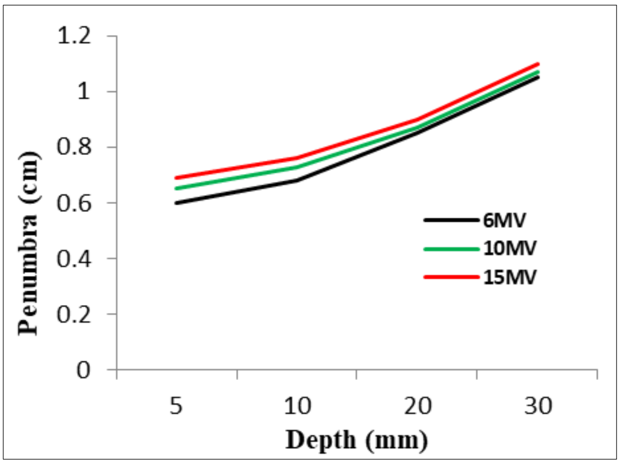

Figure 14 Variation of penumbra with depth for various photon beams with FS 10x10 cm^2

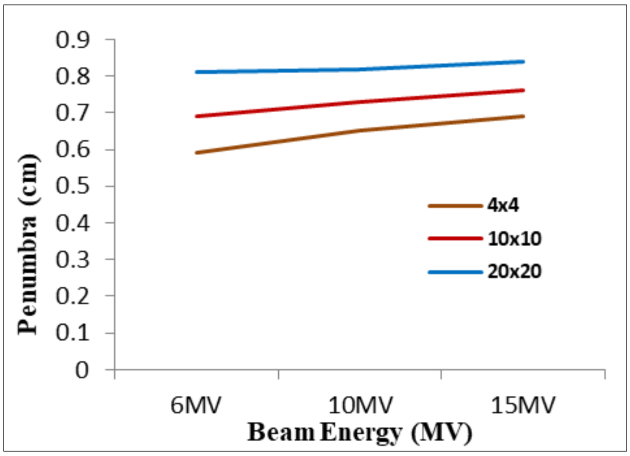

Figure 15 Variation of penumbra with FS for various photon beams at 10 cm depth

Table 1 Beam profile analysis of 6MV photon with various depths

Fields Size (cm^2)	Depth (cm)	Symmetry (%)	Flatness (%)	Penumbra (cm)	
				Left Side	Right Side
4x4	1.6	0.19	0.55	0.51	0.52
	5.0	0.28	1.00	0.55	0.56
	10.0	0.23	1.66	0.59	0.60
	20.0	0.16	2.16	0.63	0.64
	30.0	0.08	2.50	0.68	0.69
10x10	1.6	0.19	1.86	0.55	0.55
	5.0	0.24	2.33	0.60	0.61
	10.0	0.19	2.51	0.68	0.70
	20.0	0.24	3.03	0.85	0.87
	30.0	0.12	3.67	1.05	1.06
20x20	1.6	0.09	2.20	0.58	0.57
	5.0	0.03	2.46	0.74	0.76
	10.0	0.04	2.65	0.80	0.83
	20.0	0.07	3.35	1.02	1.03
	30.0	0.09	3.84	1.28	1.30

Table 2 Beam profile analysis of 10MV photon with various depths

Fields Size (cm^2)	Depth (cm)	Symmetry (%)	Flatness (%)	Penumbra (cm)	
				Left Side	Right Side
4x4	2.4	0.14	1.34	0.58	0.60
	5.0	0.08	2.11	0.61	0.63
	10.0	0.25	2.57	0.64	0.67
	20.0	0.11	3.08	0.69	0.70
	30.0	0.03	3.63	0.72	0.75
10x10	2.4	0.02	2.23	0.62	0.62
	5.0	0.02	2.44	0.65	0.67
	10.0	0.05	2.62	0.73	0.74
	20.0	0.01	3.63	0.87	0.86
	30.0	0.05	4.40	1.07	1.06
20x20	2.4	0.11	2.42	0.63	0.64
	5.0	0.22	2.60	0.68	0.70
	10.0	0.10	2.75	0.82	0.82
	20.0	0.19	3.98	1.11	1.12
	30.0	0.13	4.87	1.36	1.37

Table 3 Beam profile analysis of 15MV photon with various depths

Fields Size (cm^2)	Depth (cm)	Symmetry (%)	Flatness (%)	Penumbra (cm)	
				Left Side	Right Side
4x4	2.9	0.13	1.83	0.62	0.62
	5.0	0.30	2.26	0.65	0.67
	10.0	0.01	2.81	0.69	0.69
	20.0	0.34	3.40	0.74	0.76
	30.0	0.33	4.10	0.79	0.78
10x10	2.9	0.05	2.17	0.66	0.66
	5.0	0.02	2.57	0.69	0.70
	10.0	0.03	2.90	0.76	0.76
	20.0	0.05	3.75	0.90	0.89
	30.0	0.11	4.63	1.10	1.11
20x20	2.9	0.07	2.29	0.70	0.71
	5.0	0.01	2.56	0.73	0.74
	10.0	0.03	2.97	0.84	0.84
	20.0	0.03	3.92	1.17	1.18
	30.0	0.10	4.92	1.41	1.42

Table 4 Beam profile analysis of various photon energies at 10 cm depth and 10x10 cm^2 FS

Photon Energy (MV)	Symmetry (%)	Flatness (%)	Penumbra (cm)
6MV	0.19	2.51	0.69
10MV	0.05	2.62	0.73
15MV	0.03	2.90	0.76

Table 5 Beam profile analysis of 6MV photon with various field sizes

Depth (cm)	Fields Size (cm2)	Symmetry (%)	Flatness (%)	Penumbra (cm)
5.0	4x4	0.28	1.00	0.55
	10x10	0.24	2.33	0.60
	20x20	0.03	2.46	0.75
10.0	4x4	0.23	1.66	0.59
	10x10	0.19	2.51	0.69
	20x20	0.04	2.65	0.81

Table 6 Beam profile analysis of 10MV photon with various field sizes

Depth (cm)	Fields Size (cm2)	Symmetry (%)	Flatness (%)	Penumbra (cm)
5.0	4x4	0.08	2.11	0.62
	10x10	0.02	2.44	0.66
	20x20	0.22	2.60	0.69
10.0	4x4	0.25	2.57	0.65
	10x10	0.05	2.62	0.73
	20x20	0.10	2.75	0.82

Table 7 Beam profile analysis of 15MV photon with various field sizes

Depth (cm)	Fields Size (cm2)	Symmetry (%)	Flatness (%)	Penumbra (cm)
5.0	4x4	0.30	2.26	0.66
	10x10	0.02	2.57	0.69
	20x20	0.01	2.56	0.73
10.0	4x4	0.01	2.81	0.69
	10x10	0.03	2.90	0.76
	20x20	0.03	2.97	0.84

The beam symmetry and flatness (at 10 cm depth with field size 10x10 cm^2 and SSD 100 cm) of photon beams estimated in this study are inside the limit of tolerance 2% and 3% respectively according to the manufacturers and IEC specifications [5]. Besides some rare cases (for field size 20 x 20 cm^2 with 30 cm depth), all the measurements of penumbra width are within accepted limit of 1.2 cm [10].

4. Conclusion

This study examined the beam profile characteristics of a Varian linear accelerator at TMSS Cancer Center, Bogura, Bangladesh, for photon energies of 6 MV, 10 MV, and 15 MV. Beam profile measurements were conducted for various field sizes (4 × 4, 10 × 10, and 20 × 20 cm^2) and reference depths. The results showed that beam symmetry and flatness for all tested photon energies were within the clinically acceptable tolerance limits specified by the manufacturer and IEC standards. Specifically, symmetry values ranged from 0.01% to 0.30%, and flatness values were within 2.51% to 2.90%. Penumbra width generally increased with depth, field size, and beam energy, with values mostly within the acceptable limit of 1.2 cm, except for larger field sizes at greater depths. Overall, the Varian linear accelerator demonstrated consistent and reliable beam profiles across different photon energy levels, ensuring precise and effective radiotherapy treatments.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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