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Original research article

Analysis of physical parameters and determination of inflection point for Flattening Filter Free beams in medical linear accelerator

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ABSTRACT

Background: Medical Linear accelerators manufactured without flattening filters are increasing popular in recent days. The removal of flattening filter results in increased dose rate, reduced mean energy, reduction in head leakage and lateral scattering, which have shown advantageous when used for special treatment procedures.
Aim: This study aims to analyze physical parameters of FFF beams and to determine the inflection point for standardizing the beam flatness and penumbra.
Materials and methods: The beam profiles and depth dose patterns were measured using Radiation Field Analyzer (RFA) with 0.13 cc cylindrical ion chamber. The beam energy characteristics, head scatter factor (Sc) were obtained for 6FFF and 10FFF beams and compared with 6 MV and 10 MV photons, respectively. The symmetry and stability of unflattened regions were also analyzed. In addition, the study proposes a simple physical concept for obtaining inflection point for FFF beams and results were compared using the Akima spline interpolation method. The inflection point was used to determine the field size and penumbra of FFF beams.
Results: The Sc varied from 0.922 to 1.044 for 6FFF and from 0.913 to 1.044 for 10FFF with field sizes from 3 cm × 3 cm to 40 cm × 40 cm which is much less than FF beams. The obtained value of field size and penumbra for both simple physical concept and Akima spline interpolation methods is within the ±1.0 mm for the field size and ±2 mm penumbra. The results indicate that FFF beams reduce Sc compared with FF beams due to the absence of a flattening filter.
Conclusion: The proposed simple method to find field size and penumbra using inflection point can be accepted as it is closely approximated to mathematical results. Stability of these parameters was ascertained by repeated measurements and the study indicates good stability for FFF beam similar to that of FF beams.

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1. Background

Low LET photon irradiation with linear accelerators has become a standard of care in the management of cancers at various sites. Conventionally, the useful radiation beam passes through a beam homogenization filter or beam flattening filter (FF) resulting in a flat beam profile. It is introduced into the path of the beam to reduce excess radiation intensity of bremsstrahlung radiations originating from the transmission target.[1,2]

In the recent past, linear accelerators have been manufactured without flattening filters as additional option known as Flattening Filter Free (FFF) beams. The removal of a flattening filter results in increased dose rate, reduced mean energy, reduction in head leakage and lateral scattering, which have all shown advantageous in special treatment procedures.[3] Different vendors have different target and beam transport designs to suit the need of customers. The beam profiles generated from these linacs vary in output pattern. The different types of variation in physical parameters encountered are variable intensity profiles, variable energy profiles, change in output factors and change in depth doses relating to their differences in collimator settings. When a flattening filter is removed and the beam becomes an FFF beam, then there are no beam hardening effects. The virgin bremsstrahlung beam has slightly reduced the central axis percentage depth dose (CADD) pattern, which is again field size dependent. Georg et al.[5] in their review brought out the pattern of spectra for FF and FFF X-ray beams, indicating two effects – (1) increase in photon energy fluence for FFF beams associated with increased dose/pulse and (2) off axis spectra are not much different from that of the central axis for the FFF beam in contrast to a significant shift in spectrum due to the introduction of the flattening filter. Intensity of the FFF beam is analyzed by measuring intensity patterns available from different linear accelerators with respect to nominal field sizes and inhomogeneity patterns. The theoretical estimates of beam intensity patterns have been reported in the literature.[4–6] Kragl et al. have investigated the effect of surface dose.[7] According to their study, for field sizes smaller than 15 cm^2, surface doses at d_{max} increase for unflattened beams with maximum differences of 7% for 6 MV and 25% for 10 MV. For a 30 cm × 30 cm field, surface dose decreased by about 10% for FFF beams. As the diverging beam gets collimated by primary, secondary and tertiary collimators, they project an entrance field outline on the skin of the patient, defined as a radiation field size. In determining the penumbral widths of unflattened beams, the concept of spatial distance between 80% and 20% dose values used for conventional beams is no longer valid.[8] To overcome this problem, Ponisch et al.[4] introduced a normalization method that allows the calculation of the penumbra of an unflattened beam as well as a direct comparison with those of flattened profiles. More specifically, unflattened beam profiles were rescaled according to the ratio of the dose values at the inflection points in the penumbral region. FFF beams are commonly used to treat many malignancies including reirradiation.[9]

2. Aim

The earlier studies have not determined field size and stability of physical parameters of FFF beams. To acquire this knowledge, we studied the properties of flattened and unflattened beams of 6 and 10FFF photon fields, and a simple physical concept for obtaining inflection point (IP) for FFF beams is proposed. The results were compared using the Akima spline interpolation method. The obtained results of inflection point were then used to determine the field size and penumbra of FFF beams.

3. Materials and methods

The installed linear accelerator (True Beam™ from Varian Inc., USA) has (a) flattening filter (FF) beam photon energies of 6, 10, and 15 MV, (b) FFF photon energies of 6 and 10FFF MV, and (c) 7 electron energies of 4, 6, 9, 12, 15, 18, and 22 MeV. The beam profiles and depth dose patterns were measured using a Radiation Field Analyzer (RFA) from IBA, Germany with 0.13 cc cylindrical ion chamber for both reference and filed measurements. For the determination of symmetry, stability of the beam, field size and penumbra, dose profiles were scanned for a field size (FS) of 20 cm × 20 cm, 10 cm depth and Source to Chamber Distance (SCD) 100 cm.

4. Beam energy characteristics

4.1. *Quality index*

The purpose of measuring the quality index is to ensure that radiation energy has not changed significantly. By measuring the tissue–phantom ratio (TPR), it is possible to assess the photon beam quality. Three exposures (100 MU each) are made with gantry angle 0°, Source to Axis Distance (SAD) 100 cm and FS 10 cm × 10 cm using a calibrated 0.6 cc ionization chamber positioned at the isocenter at depths of 10 and 20 cm in a water phantom. The ionization ratio at the depth of 20 cm to that of 10 cm is known as quality index. The quality index is dependent on beam energy and it increases linearly with photon beam energy. The measurement was done for both FF and FFF photons (6 and 10 MV).

4.2. *Percentage depth dose at 10 cm*

The percentage depth dose value at 10 cm in a 10 cm × 10 cm photon beam with a Source to Skin Distance (SSD) of 100 cm, $\%DD_{10}$ is considered as a beam quality indicator and is endorsed in absolute dose measurement in AAPM TG51 protocol. In this study, we analyzed %DD(10) for both FF and FFF of 6 and 10 MV photon beams using 0.6 cc cylindrical chamber.

4.3. *Depth of dose maximum (d_{max})*

Depth of dose maximum (d_{max}) depends on the beam energy and beam field size. Nominal values for d_{max} ranges from 0 to 5 cm (orthovoltage X-ray beams to 25 MV photon beams) were extensively reported in literature.[1,2] This study presents d_{max} for a reference FS 10 cm × 10 cm at SSD 100 cm, for both FF and FFF of 6 and 10 MV photon beams.

4.4. *Scatter factor*

The values of Sc were determined with a PTW ionization chamber (type 31003, volume 0.125 cc) and an in-house polystyrene mini-phantom (diameter 3 cm). Scatter factors for field sizes (5 cm × 5 cm to 40 cm × 40 cm) were normalized to the 10 cm × 10 cm reference field for FF and FFF beams. The measurement was done for both FF and FFF with 100 cm SAD at 10 cm depth for different field sizes.

4.5. *Symmetry of the beam*

Symmetry is defined as the maximum ratio within the flattened region, multiplied with 100 (as per IEC 60976 protocol). The dose profile was acquired for a field size 20 cm × 20 cm at 100 SAD, 10 cm depth. The measurements were repeated over a period of 9 months to find its stability.

4.6. *Stability of the beam*

To quantify the stability of FFF beams, lateral distance from the central axis at 90%, 75% and 60% dose points on either side of the beam profile were recorded (Fig. 1). The measurements were repeated over a period of 9 months to find its consistency. The profile scan was acquired for 20 cm × 20 cm FS, SAD 100 cm at 10 cm depth.

4.7. *Field size*

FFF high energy photon beams have radial intensity distribution with high intensity in the center and progressively falling pattern toward the edge. This is due to the forward moving nature of high energy photons.[1,2] In general, field size for FF photon beams is defined at 50% of intensity level along the central axis. In FFF beam the 50% intensity level occurs at high gradient region (sharply descending part) of the beam profile. Field size for FFF beams does not follow the standard definition. The geometrical field size was defined by a collimator setting and radiation field size was defined through lateral separation between inflection points (IPs) along the central axis. IP is a point, where the progression of dose deposition changes its direction geometrically from positive to negative or vice versa. In this study, a simple physical concept for obtaining IP of FFF beams is proposed. IP calculated with the new concept was compared with the Akima spline interpolation method. The measurement profile acquired for the collimator field size of 20 cm × 20 cm at 100 SAD at 10 cm depth. A scatter plot in Microsoft Excel sheet was created with acquired profile as shown in Fig. 2.

An approximation method to find IP for the FFF beams profiles was proposed. In this method, normalized %DD is plotted against off-axis distances to determine the inflection point. The location of the starting point (S) and end point (E) of the high gradient region of the beam profile is described (Fig. 2). The separation between S and E is the height (*h*) of the high gradient region of the beam profile. The mid position of the IP is located at *h*/2 from either location (S or E).

To verify our approximation method with the mathematical inflection point, we used the Akima Spline Interpolation

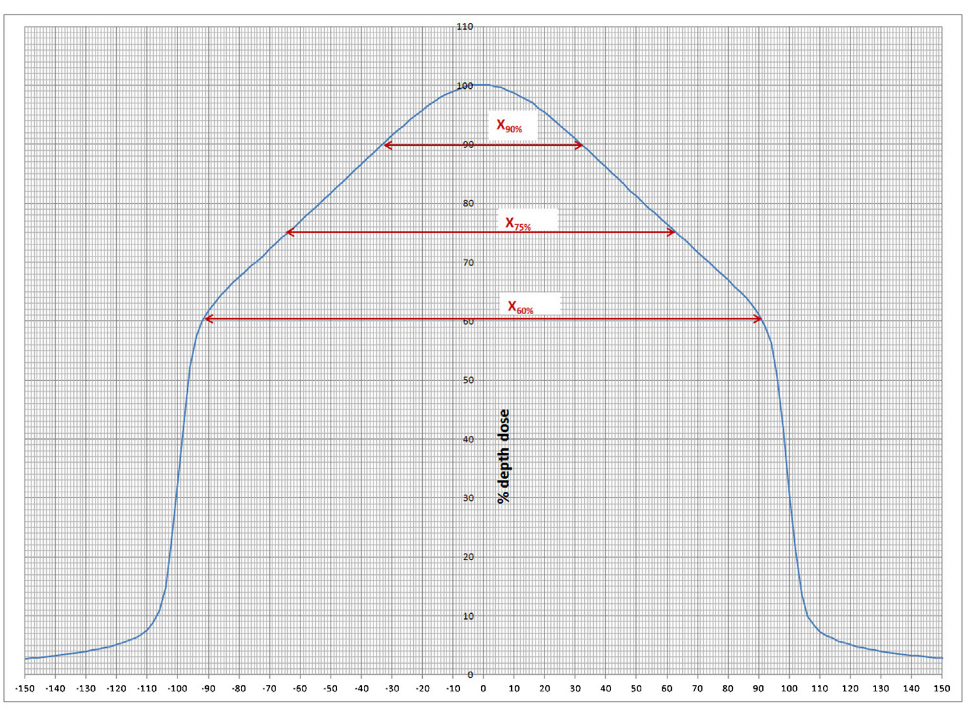

Fig. 1 – Diagram showing lateral distances at 90%, 75% and 60% dose points on the beam profile.

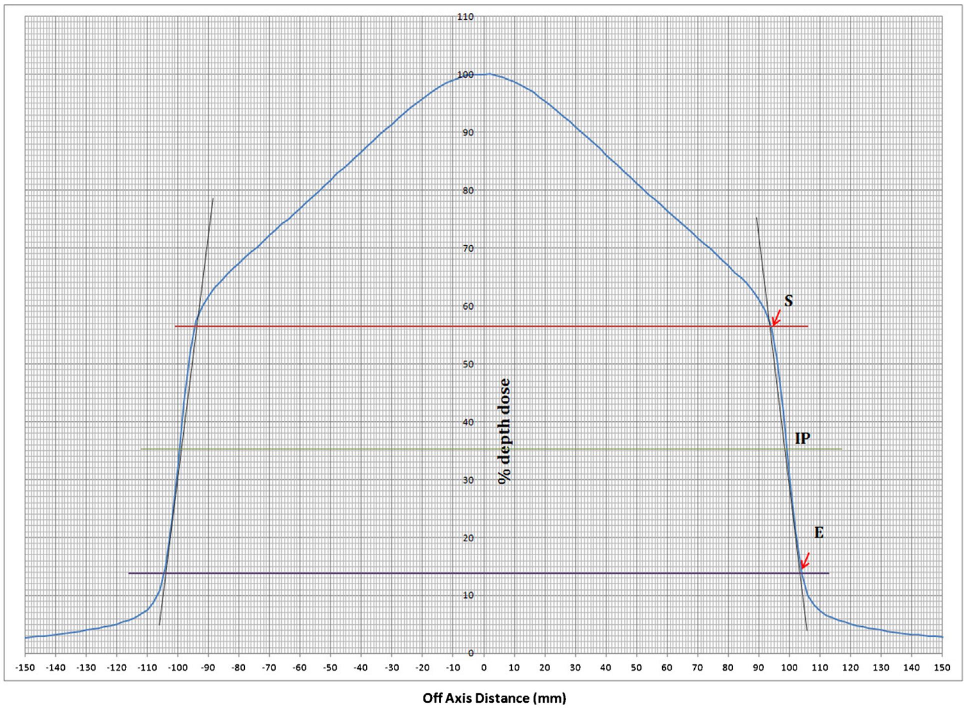

Fig. 2 – Graphical representation of the starting point (S) and end point (E).

(ASI) method (InterReg Kroll software, Germany version 2.2.0). It is a special spline which is stable to the outliers. In this study, the cubic splines method was not used since it can oscillate in the neighborhood of an outlier. Fig. 3 shows the advantage of the ASI method. The cubic spline with boundary conditions is indicated in green-color. On the intervals, which are next to the outlier, the spline noticeably deviates from the given function – because of the outlier. ASI is indicated in red. Compared to the cubic spline, the ASI is less affected by the outliers. The dose profile (20 cm × 20 cm FS, 100 SAD, 10 cm depth) was imported to the InterReg software to determine the inflection point (Fig. 4). Field size for a FFF photon beam is the lateral distance between left and right inflection points.

4.8. *Beam penumbra*

To determine penumbra, dose value at IP (mathematical method and manual approximation method) was taken as Reference Dose Value (RDV). Points P_a and P_b located at 1.6 and 0.4 times of RDV, respectively, were identified. The separation between P_a and P_b on either side of the profile was measured as the penumbra. The penumbra was indicated along the central axis for 6FFF (Fig. 5). The measurement profile acquired for the field size 20 cm × 20 cm at 100 cm SAD at 10 cm depth.

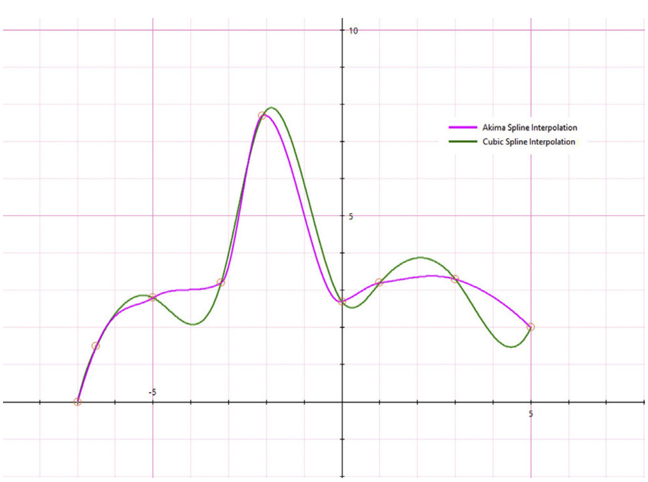

Fig. 3 – Picture illustrating the Akima spline interpolation method.

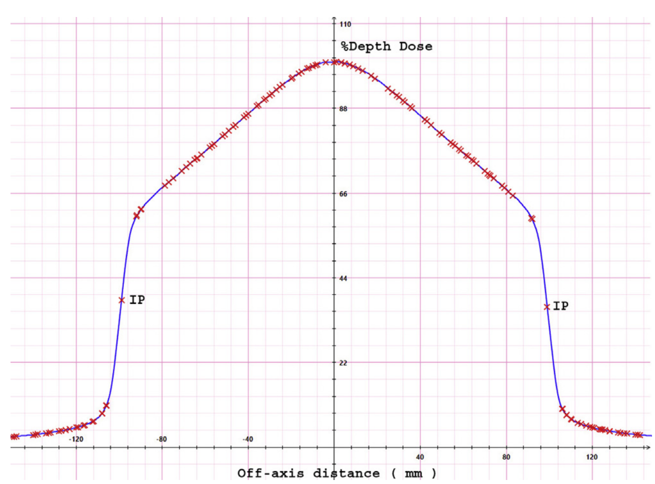

Fig. 4 – Inflection point from InterReg software.

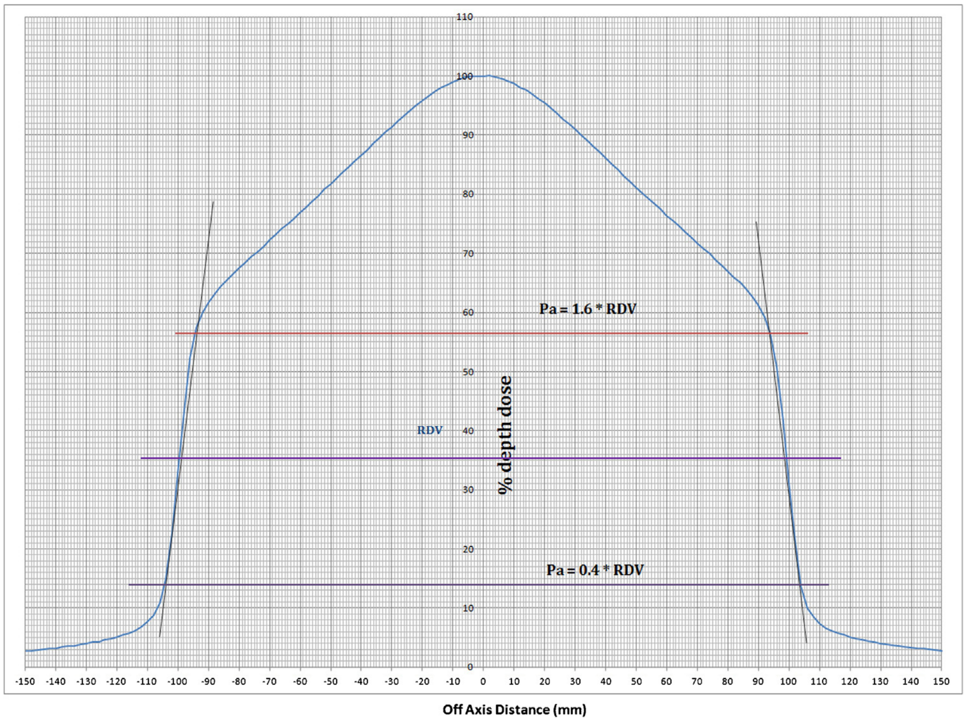

Fig. 5 – Penumbra definition.

Table 1 – Beam energy characteristic for 6FFF and 10FFF.

Photon beam	Quality index $TPR_{20,10}$	Depth of dose maximum (cm) Measured Present work	% depth dose at 10 cm Measured Present work
6FF	0.6710	1.6	67.1
6FFF	0.6293	1.49	64.1
10FF	0.7370	2.5	74.3
10FFF	0.7042	2.43	71.8

*$TPR_{20,10}$ of earlier work (6) were 0.631 (6FFF); 0.692 (10FFF); 0.667 (6FF); 0.738 (10FF).

5. Results

5.1. *Beam energy characteristics*

The beam energy characteristics such as quality index (QI), depth dose maximum and percentage of depth dose at 10 cm of the FF and FFF beams are presented in Table 1 which gives the summary of CADD pattern for FF and FFF beams for the standard field size 10 cm × 10 cm. The depth of dose maximum and depth dose at 10 cm measurement were acquired for the reference field size 10 cm × 10 cm at 100 cm SSD.

5.2. *Scatter factors*

The values of Sc for FFF and FF beams were determined at different field sizes. The obtained values were normalized to 10 cm × 10 cm field and results are presented in Table 2. The results show that FF has produced more head scatter compared to FFF.

5.3. *Symmetry*

Symmetry of 6FFF and 10FFF beams was measured for a field size of 20 cm × 20 cm at 100 cm, 10 cm depths for the flattened region (80% intensity level) (Table 3). In-Plane and Cross-Plane measurements were repeated. The maximum variation in

Table 2 – Measured head scatter for FF and FF beams.

Field size (cm^2)	Sc			
	6FF	6FFF	10FF	10FFF
5 × 5	0.844	0.830	0.8489	0.964
8 × 8	0.961	0.940	0.9735	0.9893
10 × 10	1.000	1.000	1.000	1.000
15 × 15	1.0473	1.0132	1.0298	1.0169
20 × 20	1.0648	1.0239	1.0413	1.0269
25 × 25	1.0752	1.0311	1.0475	1.0336
30 × 30	1.0823	1.0378	1.0519	1.0406
35 × 35	1.0851	1.0429	1.0525	1.044
40 × 40	1.0844	1.0443	1.0536	1.0438

Table 3 – Symmetry for FFF beams.

Different day of measurement	6FFF symmetry		10FFF symmetry	
	Cross-Plane Measured (%)	In-Plane Measured (%)	Cross-Plane Measured (%)	In-Plane Measured (%)
Measurement 1	100.86	100.97	100.92	100.70
Measurement 2	100.55	100.57	100.90	100.50
Measurement 3	101.50	101.23	100.50	100.40
Measurement 4	101.00	100.80	100.80	100.80
Measurement 5	101.00	100.50	100.70	101.00

Table 4 – Degree of 6FFF beam compared with baseline value.

Different day of measurement	6FFF Cross-Plane for 20 cm × 20 cm						6FFF In-Plane for 20 cm × 20 cm					
	$X_{90\%}$		$X_{75\%}$		$X_{60\%}$		$X_{90\%}$		$X_{75\%}$		$X_{60\%}$	
	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)
Baseline	9.91	–	17.42	–	19.36	–	9.83	–	17.24	–	19.32	–
1	9.93	−0.02	17.4	0.02	19.28	0.08	9.82	0.01	17.14	0.1	19.21	0.11
2	9.91	0	17.42	0	19.38	−0.02	9.93	−0.1	17.4	−0.16	19.31	0.01
3	9.88	0.03	17.33	0.09	19.38	−0.02	9.96	−0.13	17.27	−0.03	19.29	0.03
4	9.91	0	17.37	0.05	19.39	−0.03	10	−0.17	17.38	−0.14	19.28	0.04
5	9.9	0.01	17.33	0.09	19.38	−0.02	9.94	−0.11	17.27	−0.03	19.29	0.03

symmetry was 0.26% in Cross-Plane and 0.32% in In-Plane for 6FFF. 10FFF had a Cross-Plane symmetry of 0.28% and In-Plane symmetry of 0.25%.

5.4. *FFF beam stability*

The stability of FFF for both In-Plane and Cross-Plane profiles was obtained for the 20 cm × 20 cm field size at 100 cm SAD and 10 cm depth. The lateral distance from the central axis at 90% ($X_{90\%}$), 75% ($X_{75\%}$) and 60% ($X_{60\%}$) dose points on either side of the beam profile was measured for 6FFF and 10FFF beam energies. The measurement was repeated in consecutive days and the deviation observed was tabulated (Tables 4 and 5).

The maximum variation observed for $X_{90\%}$, $X_{75\%}$, $X_{60\%}$ with 6FFF and 10FFF were 0.03 cm, 0.09 cm, 0.08 cm (Cross-Plane), −0.17 cm, −0.16 cm, 0.11 cm (In-Plane) and 0.03 cm, −0.08 cm, 0.02 cm (Cross-Plane), 0.18 cm, −0.11 cm, −0.1 cm (In-Plane), respectively.

5.5. *Field size*

To find the radiation field size of actual collimator opening for 6FFF and 10FFF, the separation between starting point (S) and end point (E) i.e., height (h) of the high gradient region of the beam profile was determined. The IP located at $h/2$ from either side of the location were taken for determining the field size. For the 20 × 20 cm field size at 100 SAD at 10 cm depth, the field size was measured (Tables 6 and 7). The field size measurements were checked for different days for both In-Plane and Cross-Plane profiles and the observed differences between the mathematical method and approximation method. Maximum variation observed with 6FFF and 10FFF was 0.06 cm (Cross-Plane), −0.05 cm (In-Plane) and −0.07 cm (Cross-Plane), −0.05 cm (In-Plane), respectively.

5.6. *Penumbra*

To find the penumbra, the separation between P_a and P_b on either side of the profile was determined for the

Table 5 – Degree of 10FFF beam compared with baseline value.

Different day of measurement	10FFF Cross-Plane for 20 cm × 20 cm						10FFF In-Plane for 20 cm × 20 cm					
	$X_{90\%}$ (cm)		$X_{75\%}$ (cm)		$X_{60\%}$ (cm)		$X_{90\%}$ (cm)		$X_{75\%}$ (cm)		$X_{60\%}$ (cm)	
	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)	Measured (cm)	Diff. (cm)
Baseline	6.43	–	12.58	–	18.34	–	6.56	–	12.61	–	18.21	–
1	6.43	0	12.72	−0.14	18.32	0.02	6.41	0.15	12.49	0.12	18.28	−0.07
2	6.44	−0.01	12.61	−0.03	18.44	−0.1	6.56	0	12.53	0.08	18.32	−0.10
3	6.44	−0.01	12.62	−0.04	18.36	−0.02	6.41	0.15	12.63	−0.02	18.26	−0.05
4	6.44	−0.01	12.63	−0.05	18.35	−0.01	6.38	0.18	12.72	−0.11	18.28	−0.07
5	6.4	0.03	12.66	−0.08	18.34	0	6.44	0.12	12.61	0	18.25	−0.05

Table 6 – Field size constancy measurement for 6FFF.

Different day of measurement	Field size (6FFF Cross-Plane)			Field size (6FFF In-Plane)		
	Approximation method (cm)	Mathematical method (cm)	Variation (cm)	Approximation method (cm)	Mathematical method (cm)	Variation (cm)
Baseline	19.90	19.90	0	19.85	19.90	−0.05
1	19.85	19.88	−0.03	19.80	19.83	−0.03
2	19.95	19.89	0.06	19.80	19.85	−0.05
3	19.90	19.90	0	19.85	19.87	−0.02
4	19.92	19.89	0.03	19.85	19.85	0
5	19.93	19.89	0.04	19.83	19.85	−0.02

Table 7 – Field size measured at different days for 10FFF.

Different day of measurement	Field size (10FFF Cross-Plane)			Field size (10FFF In-Plane)		
	Approximation method (cm)	Mathematical method (cm)	Variation (cm)	Approximation method (cm)	Mathematical method (cm)	Variation (cm)
Baseline	19.90	19.92	−0.02	19.80	19.81	−0.01
1	19.95	19.96	−0.01	19.80	19.85	−0.05
2	19.95	19.85	0.1	19.80	19.84	−0.04
3	19.80	19.87	−0.07	19.80	19.83	−0.03
4	19.90	19.80	0.1	19.82	19.87	−0.05
5	19.90	19.90	0	19.82	19.82	0.00

Table 8 – Penumbra measured for 6FFF beam in different days.

Measurement in different days			1	2	3	4	5
Penumbra left (mm)	Cross-Plane	Approximation method (mm)	8.00	8.00	8.00	8.00	8.50
		Mathematical method (mm)	8.41	8.47	8.38	8.40	8.00
		Difference (mm)	−0.41	−0.47	−0.38	−0.4	0.5
	In-Plane	Approximation method (mm)	9.00	9.00	8.50	8.5	9.00
		Mathematical method (mm)	10.4	9.15	9.15	9.00	9.05
		Difference (mm)	−1.4	−0.15	−0.65	−0.5	−0.05
Penumbra right (mm)	Cross-Plane	Approximation method (mm)	8.00	8.40	8.50	8.00	8.00
		Mathematical method (mm)	8.74	8.19	8.20	8.15	8.20
		Difference (mm)	−0.74	0.21	0.3	−0.15	−0.2
	In-Plane	Approximation method (mm)	8.50	9.00	8.5	9.00	9.00
		Mathematical method (mm)	9.92	9.31	9.32	9.23	9.12
		Difference (mm)	−1.42	−0.31	−0.82	−0.23	−0.12

mathematical method and approximation method. The penumbra was indicated along the central axis for 6FFF and 10FFF beam energies. For the set collimator field size of 20 cm × 20 cm at 100 cm SAD at 10 cm depth, the right side penumbra and left side penumbra is measured and are presented in Tables 8 and 9. The measurement was repeated for In-Plane and Cross-Plane in consecutive days and the penumbra measurements and difference observed were tabulated. A

Table 9 – Penumbra measured for 10FFF beam in different days.

Measurement in different days			1	2	3	4	5
Penumbra left (mm)	Cross-Plane	Approximation method (mm)	8.50	8.50	7.80	7.70	8.00
		Mathematical method (mm)	7.73	8.57	7.90	7.92	8.10
		Difference (mm)	0.77	−0.07	−0.10	−0.22	−0.10
	In-Plane	Approximation method (mm)	8.00	8.50	8.50	8.20	8.20
		Mathematical method (mm)	8.21	7.75	7.80	7.30	7.90
		Difference (mm)	−0.21	0.75	0.70	0.90	0.30
Penumbra right (mm)	Cross-Plane	Approximation method (mm)	8.50	8.00	8.00	7.50	7.90
		Mathematical method (mm)	8.36	8.99	8.30	8.40	8.20
		Difference (mm)	0.14	−0.99	−0.3	−0.9	−0.3
	In-Plane	Approximation method (mm)	8.00	8.00	8.50	8.00	8.00
		Mathematical method (mm)	8.20	8.17	8.30	8.25	8.30
		Difference (mm)	−0.2	−0.17	0.2	−0.25	−0.3

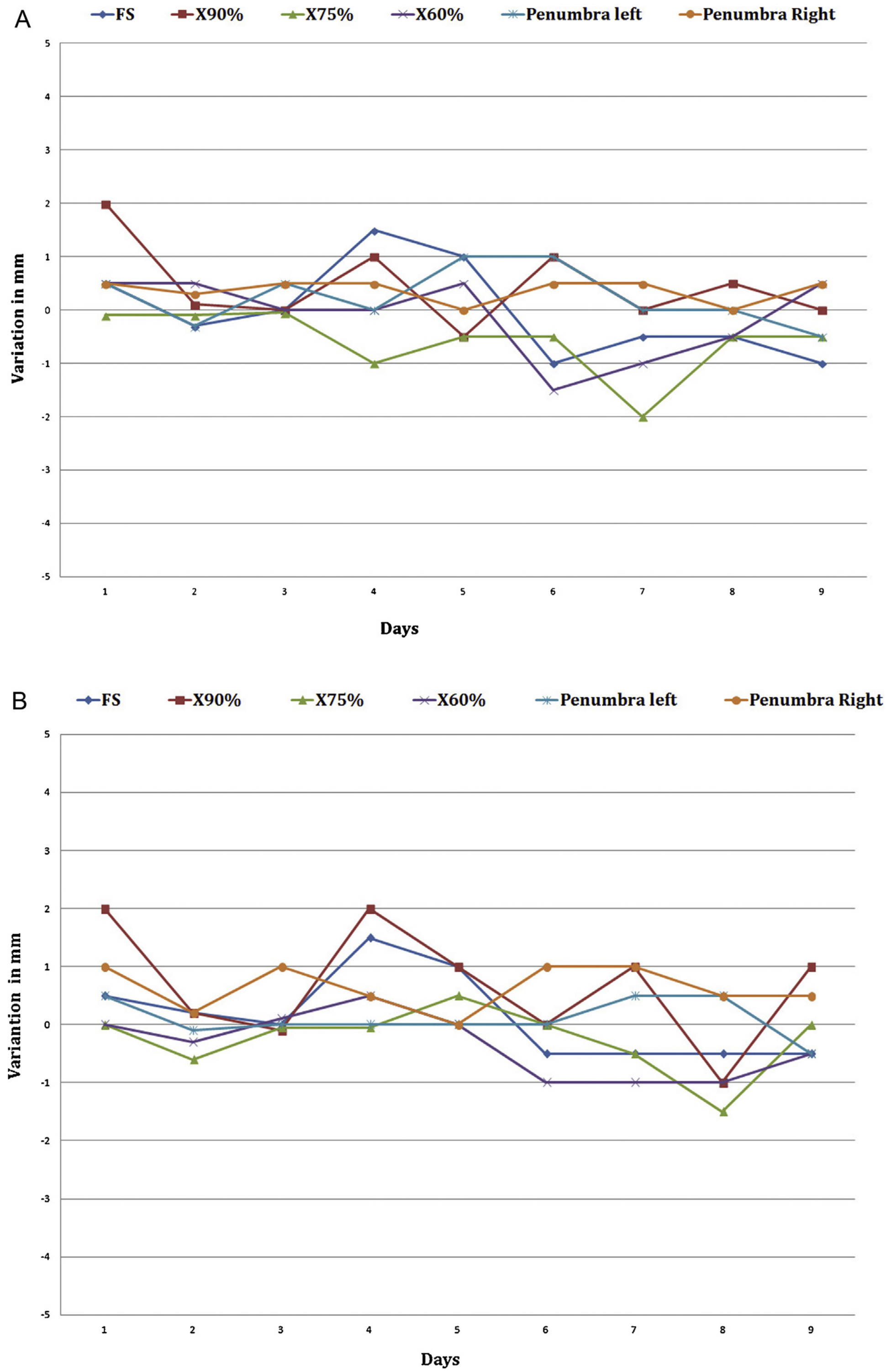

Fig. 6 – (A) In-Plane dose variation for 6FFF beam. (B) Cross-Plane dose variation for 6FFF beam.

graphical representation of variation in readings over a period of 9 months for field size, $X_{90\%}$, $X_{75\%}$, $X_{60\%}$, penumbra left and penumbra right of In-Plane and Cross-Plane are shown in Fig. 6A and B for 6FFF beam and Fig. 7A and B for 10FFF beam, respectively.

6. Discussion

The measured beam characteristics such as quality index, depth of dose at 10 cm and depth to dose maximum of the FFF beams were in good agreement with an earlier report

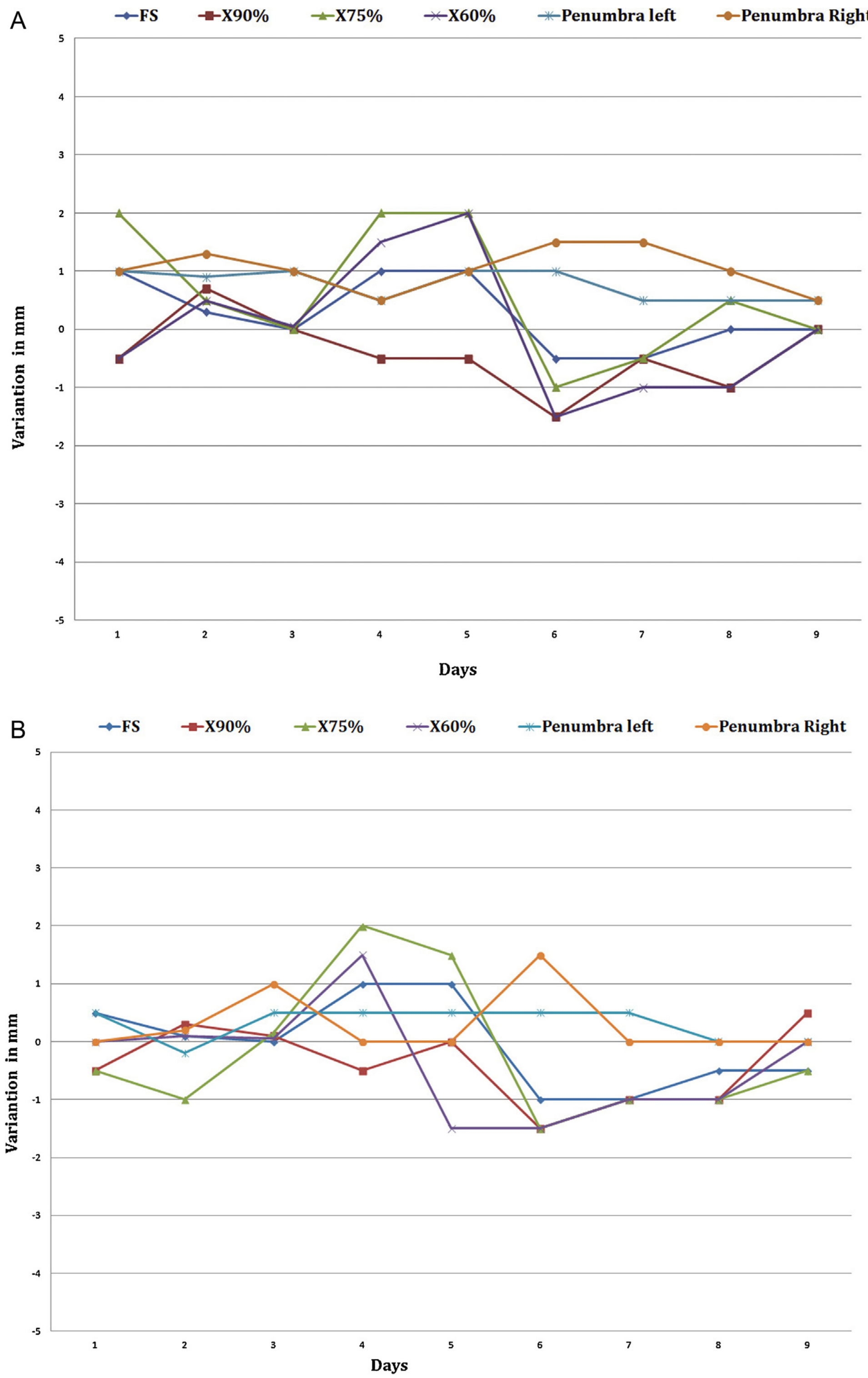

Fig. 7 – (A) In-Plane dose variation for 10FFF beam. (B) Cross-Plane dose variation for 10FFF beam.

by Hrbacek et al.[6] Acquired physical parameter data for FFF beams are equivalent to the previously published reports.[4–8]

The head scatter (Sc) varies from 0.922 to 1.044 (6FFF) and 0.913 to 1.044 (10FFF) for the field sizes from 3 cm × 3 cm to 40 cm × 40 cm (Table 2). For FF beams, corresponding head scatter (Sc) variations are 0.759 to 1.084 (6FF) and 0.784 to 1.054 (10FF). This clearly shows that head scatter predominantly arises due to the presence of flattening filter in the path of photon beams.

Symmetry of the beam was evaluated for In-Plane and Cross-Plane and the results were in agreement with in the ±1%. It could establish the reproducibility over a longer period of time. To quantify the stability of unflatness, the lateral distance from the central axis at 90%, 75% and 60% dose points on either side of the beam profile are recorded along major axes for all available beam energies. The maximum variation observed with the baseline value was 1.8 mm.

The approximation method used to determine the field size for FFF beam was cross verified by a mathematical method (ASI). The result from the manual approximation devised was similar to that of ASI. The measurements were repeated on 5 consecutive days and compared with the first day (baseline) measurement. The variation between the baseline and the measurement taken on consecutive days was less than ±1 mm for both 6FFF and 10FFF.

To quantify the penumbra, a reference dose value (RDV) was identified at IP. Thus, 1.6 (P_a) and 0.4 (P_b) times of RDV, respectively, were identified on either side of the profile to provide the measure of the penumbra. The results of penumbra were found to be within ±2 mm for the 20 cm × 20 cm field size, and reproducibility in their measurements was shown for In-Plane and Cross-Planes in Tables 8 and 9.

7. Conclusion

The results indicate that FFF beams reduce head scatter compared to FF beams. The proposed simple method to determine field size and penumbrae using an inflection point is advantageous since it approximates the mathematical results precisely. A beam stability is maintained for FFF beams similar to FF beams.

Conflict of interest

None declared.

Financial disclosure

None declared.

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