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A STUDY ON DEPTH DOSE OF FLATTENED AND FLATTENING FILTER FREE PHOTON BEAM OF MILLENNIUM TRUE BEAM LINEAR ACCELERATOR USED FOR CANCER TREATMENT

Oncology

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ABSTRACT

Aim of Study: The aim of this study is to report the variation of depth dose and surface dose of different field sizes by flattening filter free (FFF) photon beams generated by millennium True Beam medical linear accelerator used for cancer treatment and its variation with respect to flattened beams (FB).

Materials and Methods: We compare the data of photon beam (beam characterization and evolution of dosimetric properties) for two standard FB photon energy 6 MV, 10 MV verses 6 MVFFF, and 10 MVFFF FFF beam. Percentage depth dose (PDD), surface dose and Quality index were the parameters analyzed for the comparison. Surface doses were obtained for field sizes 3 × 3 - 40 × 40 cm2. For depth dose curves ionization chambers and radiation field analyser were used and data were taken at a source-to-surface distance (SSD). Consistency of data was checked for one year.

Results: Surface doses were higher in FFF beam compared with FB up to 20 × 20 cm2 field size. But in higher field size 40x40 cm2 surface dose in both 6XFFF and 6 MV FB beams are equal. For 10 MV, surface dose is higher than 10XFFF beams in higher field size 40x40 cm2. Beam quality of FFF beam was lesser in magnitude in comparison to that of FF beam and the difference of 5.54%between 6XFFF and 6 MV, and 4.45% between 10XFFF and 10 MV were observed. For PDD at 10 cm depth, the maximum percentage of variation in 1 year for 6MV and 6XFFF beams with field sizes 10 × 10 cm2 and 20 × 20 cm2 were 0.50%, 0.54%, 0.81% and 0.58% respectively. Whereas for 10 MV and 10XFFF the maximum percentage variation were observed up to 0.35% within one year.

Conclusion: The surface dose, PDD and Quality index consistency of FFF beams and FB photon beams showed good consistency during a year duration.

KEYWORDS

Field width, Flattening filter free beams, Quality Index, Surface Dose, and True Beam.

INTRODUCTION

Radiotherapy is one of the important modality for cancer treatment. Modern radiotherapy techniques like stereotactic radio surgery (SRT), intensity modulated radio surgery (IMRS), image guided radiotherapy (IGRT) and stereotactic body radiotherapy (SBRT) have become more familiar and essential for last decade to treat cancer patients in oncology management. Previously, flat beam profile was used in the Radiotherapy practice due to ease of dose computation and treatment planning. Due to longer treatment time, these techniques cause errors in reproducibility of patient position.

Gradually, the development of IMRT removes the need of flattening filter in modern linear accelerator systems. Application of the flattening filter-free (FFF) photon beam has been discussed in several literatures.[1-5] Forward peaked dose profile is the common feature of the FFF beam.[6] FFF beam has increased dose rate, reduced dose to organ-at-risk (OAR), reduced neutron contamination for high energy beams (>15 MV), and reduced uncertainty in dose calculation than that of FF beams. Thus, FFF beam reduces both treatment time and risk of secondary cancer induced by radiation.[2-4] Head scatter factor, shape of the off-axis profiles, depth dose, and output factors (OFs) are the four important issues to differ the FFF beam from FB beam.[7-10]

FFF beam can provide maximum high dose rate of 1400 MU/Mit for 6 MVFFF beam and 2400 MU/Mit for 10 MVFFF beam. Removal of flattening filter significantly increases dose rate, causes softening of beam spectrum and reduction in scatter radiation as well as a decrease in neutron and photon leakage from the head. Although, many radiotherapy centers have facility with FFF beam, but still its use is not fully implemented all around the world.[11]

Most of the studies focused on the time efficiency obtained from the high dose rate of the FFF beam compared with the flattened beam. However, the dosimetric differences between flattened beam and FFF beam are not well understood.[6] It is required to tabulate the differences of dosimetric parameters like depth dose and surface dose in FB and FFF of this new treatment unit. Depth dose helps to find out the energy of exit photon beam. Though literatures have been published on FFF, small field dosimetry, surface dose, profile analysis (field width and penumbra) and stability of FFF with different models of True beam Accelerator, but very little information is available using Millennium True beam accelerator.

In our study Millennium True Beam Linear accelerator (Varian Medical System, Palo Alto, CA) was used with available FFF beams (6XFFF and 10XFFF beams).[2,12-14] This True beam linear accelerator had been commissioned in our centre in April, 2016.

MATERIALS AND METHODS

Millennium True Beam Linear Accelerator machine is commissioned in our set-up with the help of the IBA dosimetry system in water phantom. The machine is equipped with the 120 millennium multileaf collimator (MLC), consisting of two opposing leaf banks with leaves that move along the X-axis. For the central 20 cm of the MLC, each leaf has a width of 5 mm projected at isocenter, whereas for the peripheral 20 cm on either side, the leaf width is increased to 10 mm.

Radiation field analyzer (RFA) which is a motorized water tank (PTW, Feriburg, Germany) with scanning dimensions of 48 × 48 × 48 cm^3, was used to scan the radiation field. The data were collected as per TG-106 and eclipse treatment planning system recommendations. For field sizes 5 × 5 to 40 × 40 cm^2, ionization chamber (PTW, 0.125 cc) was used to scan the radiation field. Pinpoint (PTW, 0.016 cc) chamber was used for smaller field size 3x3 cm^2. FFF and FB photon energies (6XFFF, 10XFFF and 6X, 10X) were analyzed with beam data in Millennium True Beam machine.

PDD and depth dose were calculated at SSD of 100 cm. PDD was calculated for FB and FFF beam at a depth of 10 cm with respect to maximum absorbed dose position and the data were compared with various field sizes (3x3, 4x4, 6x6, 8x8, 10x10, 20x20, 30x30 and 40x40) cm^2.

Surface dose:
The value of surface dose for any field size is calculated by the dose at the first millimeter (1 mm) of a homogeneous water phantom divided by the dose at D_{max} for the corresponding field. Surface doses were obtained by using PTW software after taking PDD scanning data from RFA for 3 ×3 to 40 × 40 cm^2 field sizes. The measured surface doses for were compared between the flattening filter 6 MV, 10 MV and flattening filters free 6 MVFFF, 10 MVFFF beam. Exit energy spectrum and electron contaminations are the two factors, which can change the surface dose in FFF in compared to FB beam. Surface dose is measured at a depth of 5 mm with respect to dose at dose maximum position (D_{max}) as per literature available.[15,16]

Data consistency:
Every four months data consistency checked during one year for Surface dose (D_s), Quality Index of beam (QI), and Percentage depth dose at 10 cm depth (D_{10}). Every time the data were taken at different times of the day to check the data consistency.

RESULTS
Surface doses were varied with different energies with respect to different field sizes. The change in surface dose between 6X and 10X in FFF mode was due to the photon spectrum depending on the conditions such as nominal photon energy, structures in the gantry head, point of measurement, and collimator field sizes, difference in electron contamination, lateral photon fluence, internal scatter in the treatment head and scatter from the jaws.

For 6X, it was higher for FFF in comparison to FB up to 20x20 cm^2 field size and was equal for FFF and FB in higher field size of 40x40 cm^2. The surface dose for 6X was 6.8% and 4.5% more in FFF in comparison to FB with respect to field sizes of 10 × 10 and 20 × 20 cm^2 respectively. Whereas, the surface doses for 10X was higher in FFF and FB beams with respect to field size up to 20x20 cm^2 and field size beyond 20x20 cm^2 (figure 1). Surface doses for 10X was 9.9% and 6.10% higher in FFF with field sizes 10 × 10 and 20 × 20 cm^2 respectively.

Data consistency
Surface dose: In one year, the maximum variation in surface dose for 6X FFF and 10X FFF beams with field sizes 10 × 10 cm^2 and 20 × 20 cm^2 were 1.40%, 1.50%, 1.05% and 1.10% respectively, whereas it was 1.10%, 1.01%, 1.02% and 1.05% respectively for FB beams.

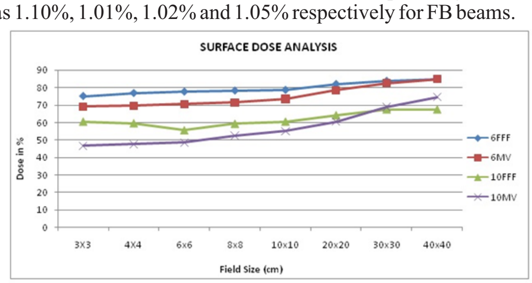

Fig1: Surface dose in flattened beams verses flattening filter free for 6 and 10 MV photon beams

Quality Index of beam (QI): The quality index also known as beam quality shows the energy of the photon beam. Here maximum variation in quality index of the beam in 1 year for 6 MV and 6X FFF beams with field sizes 10 × 10 cm^2 and 20 × 20 cm^2 are 0.30%, 0.30%, 0.30% and 0.30% respectively as per data given in table-1 whereas for 10 MV and 10XFFF the maximum variation were observed up to 0.3% as per data given in table-2 within one year. Beam quality of FFF beam found to be lesser in magnitude compared to that of FF beam. Percentage of magnitude difference in 6XFFF and 10XFFF were found to be 5.54% and 4.45% than that of 6 MV and 10 MV beams respectively.

Field Size (cm^2)	6 MV				6FFF			
	M_1	M_2	M_3	M_4	M_1	M_2	M_3	M_4
3x3	0.623	0.621	0.621	0.620	0.588	0.582	0.580	0.579
4x4	0.625	0.624	0.624	0.623	0.592	0.590	0.589	0.589
6x6	0.641	0.642	0.640	0.639	0.605	0.605	0.604	0.602
8x8	0.654	0.653	0.654	0.655	0.619	0.618	0.619	0.617
10x10	0.666	0.667	0.668	0.667	0.631	0.630	0.630	0.629
20x20	0.713	0.712	0.714	0.713	0.676	0.676	0.674	0.675
30x30	0.733	0.735	0.736	0.736	0.686	0.684	0.685	0.684
40x40	0.747	0.746	0.747	0.748	0.694	0.693	0.694	0.693

M_1: First month of the year, M_2: 4th Month of the year, M_3: 8th month of the Year and M_4: 12th month of the year

Table1: Quality Index of 6 MV and 6FFF Beams

Field Size (cm^2)	10 MV				10FFF			
	M_1	M_2	M_3	M_4	M_1	M_2	M_3	M_4
3x3	0.701	0.692	0.690	0.695	0.673	0.669	0.662	0.659
4x4	0.710	0.708	0.702	0.701	0.674	0.671	0.668	0.663
6x6	0.719	0.719	0.717	0.717	0.684	0.683	0.682	0.683
8x8	0.730	0.731	0.728	0.729	0.696	0.695	0.693	0.691
10x10	0.739	0.740	0.741	0.741	0.705	0.706	0.708	0.708
20x20	0.773	0.773	0.772	0.773	0.729	0.729	0.728	0.727
30x30	0.789	0.787	0.789	0.789	0.737	0.736	0.735	0.735
40x40	0.797	0.798	0.797	0.798	0.742	0.741	0.740	0.739

M_1: First month of the year, M_2: 4^{th} Month of the year, M_3: 8^{th} month of the Year and M_4: 12^{th} month of the year

Table 2: Quality Index of 10 MV and 10FFF Beams

Percentage depth dose at 10 cm depth (D_{10}): Percentage depth dose is the absorbed dose at any depth with respect to maximum absorbed dose position expressed in percentage. The specific D_{10} value also shows the specific energy of the photon beam as per IEC -60731 scale. Here as per data given in table-3, maximum percentage of variation in D_{10} of the photon beam in 1 year for 6MV and 6XFFF beams with field sizes 10 × 10 cm^2 and 20 × 20 cm^2 are 0.50%, 0.54%, 0.81% and 0.58% respectively. Whereas for 10 MV and 10XFFF the maximum percentage variation that were observed up to 0.35% as per data given in table-4 within one year.

Field Size (cm^2)	6 MV				6FFF			
	M_1(%)	M_2(%)	M_3(%)	M_4(%)	M_1(%)	M_2(%)	M_3(%)	M_4(%)
3x3	60.73	60.51	60.32	60.21	57.56	57.26	56.21	56.72
4x4	62.22	62.19	62.13	62.10	58.72	58.76	58.83	58.94
6x6	64.28	64.29	64.32	64.46	61.01	61.20	61.33	61.43
8x8	65.73	65.85	66.01	66.13	62.65	62.89	62.96	63.15
10x10	66.97	67.10	67.22	67.33	63.83	63.97	64.32	64.35
20x20	69.87	69.96	70.12	70.25	66.90	67.10	67.18	67.29
30x30	71.29	71.42	71.58	71.63	67.83	68.11	68.25	68.34
40x40	72.16	72.32	72.48	72.53	68.39	68.42	68.53	68.69

M_1: First month of the year, M_2: 4^{th} Month of the year, M_3: 8^{th} month of the Year and M_4: 12^{th} month of the year

Table3: Percentage depth dose at 10 cm depth (D_{10}) of 6MV and 6FFF photon beam

Field Size (cm^2)	6 MV				6FFF			
	M_1(%)	M_2(%)	M_3(%)	M_4(%)	M_1(%)	M_2(%)	M_3(%)	M_4(%)
3x3	70.56	69.85	69.05	68.73	67.27	67.10	66.52	65.68
4x4	71.10	71.15	71.18	71.25	68.28	68.23	68.16	68.15
6x6	72.98	72.91	72.89	72.83	69.23	69.42	69.58	69.87
8x8	73.49	73.65	73.71	73.84	70.73	70.95	71.10	71.19
10x10	74.16	74.22	74.26	74.29	71.27	71.41	71.62	71.89
20x20	75.49	75.62	75.73	75.84	72.78	72.91	72.96	73.02
30x30	76.10	76.23	76.49	76.60	73.27	73.41	73.56	73.67
40x40	76.68	76.86	77.01	77.09	73.45	73.61	73.85	74.05

M_1: First month of the year, M_2: 4^{th} Month of the year, M_3: 8^{th} month of the Year and M_4: 12^{th} month of the year

Table 4: Percentage depth dose at 10 cm depth (D_{10}) of 10MV and 10FFF photon beam

DISCUSSION
PDD is an energy performance indicator of a specific beam. PDD at 10 cm depth for a field size of 10 × 10 cm^2 at SSD 100 cm is a key parameter.[11] The true beam linear accelerator with flattening filter mode produces beam with different dosimetric characteristics compared to the flattened beam. The photon beam spectrum of the FFF beam contains a greater proportion of low energy photons (<1 MV) and reduction in high energy photons in comparison to the flattened

beam due to no beam hardening through the flattened filters.[2,17] Reduction in the overall PDD occurs for FFF beyond the build-up region when compared to the flattened beam with respect to the same nominal photon energy. There is decrease in variation of the dose in the build-up region by removing the flattening filters. Flattening filter is the major source of the head scatter in increased field size.[18] The dose from contaminant electrons is expected to increase due to unfiltered electrons from the target.[19,20] The correction of off-axis beam softening is not required for FFF beam due to significant reduction in variation of the photon spectrum along off-axis.

AERB TG recommended lateral width of 90%, 75%, and 60% of the beam profile to quantify the magnitude of the degree of un-flatness of FFF beam. Shende et al. in a study found that lateral separations are more for lower energy FFF beam in comparison to that of high energy FFF beam and width becomes saturated as become down on the profile, and such difference is possibly due to the off-axis softening effect in FFF beams.[11]

Total output factor (Scq) is the product of collimator scatter (Sc) and phantom scatter (Sp) factor and at a smaller field sizes for FFF beam it is slightly higher in magnitude compare to that of FF beam. Whereas, there is no significant difference in Scp at smaller field sizes for 6 MVFFF beam compared to 6 MV and as the field size were increased above 10×10 cm^2, increase in Scp values for (6 MV, 10 MV) FF beam compared to (6 MVFFF, 10 MVFFF) FFF beams were observed.[21] Collimator scatter (Sc) is the dominant factor at lower field sizes, whereas it was phantom scatter (Sp) at higher field sizes. Such difference in two different curves is due to the reduction in head scatter contribution and significant difference shows an important role of flattening filter.

MLC transmission and dosimetric leaf gap are the important parameters during configuration of MLC in the treatment planning system and both the parameters increases with increase in beam energy and the inadequate dosimetric leaf gap could cause dosimetric errors in the PTV and Organ at Risk.

Removal of flattening filter alters the physics around flattening beam such as: significant increases in dose rate, softening of beam spectrum and reduction in scatter radiation and electron contamination as well as a decrease in neutron and photon leakage from the head resulting decrease in surface dose.

Variations of the surface doses for 6X and 10X is due to photon energy, photon spectrum, electron contamination, backscatter to monitor chamber, lateral photon fluence fall-off in FFF and FB beams. In the present study, surface doses were higher in FFF beam compared with FB up to 20×20 cm^2 field size. But in higher field size 40x40 cm^2 surface dose in both 6FFF and 6 MV FB beams are equal, whereas, surface dose is higher in 10MV than 10FFF beams in this higher field size (40x40cm^2).FFF beams showed good data consistency in one year duration. Our result matches with the conclusion made by Muralidhar et al with separate varian ST_X True beam linear accelerator.[22]

In true beam setup softening of beam spectra and loss of beam hardening effect yield reduction in PDD at 10 cm. Reduction in PDD at 10 cm for 6XFFF and 10XFFF beam from their corresponding 6X and 10X FF beam were observed 4.52% and 3.62% respectively for field size 10x10 cm^2 and the data was supported by Shende et al. where it was 4.35% and 5.30% respectively.[11] Also, evaluated data on PDD in our study were supported by the various published literature.[23,24] The quality index of FFF beam is lesser in magnitude compared to that of FF beam. In our study, percentage of magnitude difference in 6XFFF and 10XFFF were found to be 5.54% and 4.45% than that of 6 MV and 10 MV beam respectively and the data was supported by Shende et al. where it was 5.42% and 4.50% respectively.[11]

Without flattening filter causes drastic changes in dose rate and shape of the beam profile. Removal of the flattening filter results in lateral softening of the beam, and cause forward peak in the center of the beam and steep gradient in the periphery. The lateral dose falloff is more in plateau of higher energy in comparison to lower energy influencing lateral variation in dose distribution and is due to the smaller scattering angles at higher energies in comparison to low energy photons.[2]

In the present study, the Quality index for 6XFFF beam is 0.630(for 6MV is 0.667) and for 10XFFF beam is 0.707 (for 10MV is 0.740) which was supported by Sahani et al., where it was 0.633 (for 6MV was 0.667) for 6XFFF beam and 0.709 (for 10MV was 0.737) for 10XFFF beam.[25] The energy of 6XFFF beam is equal to approximately 4MV and 10XFFF beam is equal to approximately 8MV. The lower Quality Index of FFF beams in compare to FB beams are due to increase in dose rate, softening the x-ray spectra, reduction in head-scattered radiation, and the non-uniform beam profile. The softening of x-ray spectra affects the depth as well as lateral dose distribution at all depths and results in increase surface dose and decrease in Quality Index.[25] Other competitors of that company has got approximately equal Quality Index of FFF beam to FF beams because of same collimator structure.

CONCLUSION

Data on the Surface dose, Quality Index of beam and percentage depth dose at 10 cm depth consistency of FFF beams in 6XFFF and 10XFFF photon beams analyzed in Millennium True Beam linear accelerator machine providing valuable information and analysis on the characteristics of the FFF beam and the analyzed data may be useful for future reference during commissioning of the model. Variation in dosimetry data for FFF with respect to FB can be used for photon beam energy selection during radiotherapy planning. FFF beams gives rise to lesser dose in the periphery of the target compared to flattening filter beam and the patient may be benefited from decrease exposure of surrounding normal tissue. Extensive quality assurance is needed for commissioning and clinical implementation of FFF mode. Consistency and stability have been observed over the period of one year of data acquisition.

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