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Electron beam characteristics at extended source to surface distance for a Clinac-DHX linear accelerator

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A uniform dose to the target site is required with a knowledge of delivered dose, central axis depth dose and beam flatness for successful electron treatment at an extended source to surface distance (SSD). In an extended SSD treatment under dosage of the lateral tissue may occur due to reduced beam flatness. To study the changes in beam characteristics, the depth dose curves, beam flatness and isodose distributions were measured at different SSDs from 100 to 120 cm for clinically used field sizes from (4×4) to (25×25) cm^2 and beam energies ranging from 6 MeV to 20 MeV. Our results suggest that the change in depth dose is minimal except in the buildup region for most energy. In general surface dose is decreased as the SSD increased moderately. It was observed that the loss in beam flatness is significant for smaller fields, higher isodose lines, and lower energies. The penumbra enlarged and the uniformity index reduced with increasing SSD.

Key words: electron beam, beam flatness, uniformity index, beam penumbra, isodose.

Introduction

Electron beams are readily produced from the dual photon and multi electron energies linear accelerators. An electron beam is characterized by a finite range of penetration with a rapid dose fall off towards a slowly decaying X-ray background as the electrons traverse through tissues. This characteristic makes electron beams suitable for treating lesions at or close to the surface using a single field while sparing the underlying tissues.

Treatments are often carried out at standard surface distance (SSD), where the data's on the electron beams have been measured. However, in certain clinical situations for example, in the management of head and neck cancers, vulva and groin, and breast, may require extended treatment distances for electron beam as body anatomy may obstruct the positioning of the electron applicator. For an accurate dose delivery to the target volume, electron beam depth dose and beam flatness at a desired depth and extended distance should be accurately known. TG-25 [5] strongly recommends that all extended SSD treatments should be treated as a special case and institutional well defined guidelines should be used for dosimetry. Most treatment planning systems are unable to provide dose distribution accurately at the extended distances needed for clinical use. This concern may be attributing in part to the unpredictability of the angular spread of the electron beam, which may vary from accelerator to accelerator. The aim of this research work was to examine the influence of extended SSD on beam characteristics for Clinac-DHX linear accelerator.

Material and methods

Electron beams from a Varian Clinac DHX unit having energies 6, 9, 12, 16 and 20 MeV were used. A set of five cones with field sizes 4×4, 6×6, 10×10, 15×15, 20×20 and 25×25 cm^2 provided by the manufacturer were used. For each cone size, there are associated collimator jaw settings. The cones were individually optimized by the scattering foil, collimator design, and settings to provide a uniform beam at the reference SSD (100 cm). To study the beam characteristics a computerized water scanning data-acquisition system (Wellhofer Dosimetric schwazenbruek, Germany) with Electron field detector (EFD) a semiconductor diode was used to measure the data. In this study the depth dose was measured at various SSDs from 100-120 cm for all electron energies using the scanning equipment. This scanning equipment consists of the water phantom (50×50×50 cm^3) system interfaced to a personal computer. Two diodes were used in the water scanning system. One served as the reference diode while the other was used to scan electron beams in the three dimensions within the 50×50×50 cm^3 water phantom. The beam profiles were measured at six different depths including dmax (values known from respective depth dose curves) generates isodose lines using Omnipro-Accept software. The SSD was changed by lowering the water tank. Further depth dose and beam profiles were taken for each field size, beam energy and SSD. The data were analyzed and transferred to a spread sheet for further analysis. Isodose perpendicular to the beam central plane was measured using scanditronix I'matriXX device at half the therapeutic depth and the dose in that plane was normalized to 100%. The effective depth of the chamber is at a depth of 0.36 cm from the surface.

Results

The results have been analyzed for all the energies and electron cones available with the machine. However the results were presented for two energies 6 MeV and 20 MeV electron beam for 4×4 cm^2 and 10×10 cm^2 field sizes. Figures 1a, b, 1c, 1d show the depth dose curves of 6 and 20 MeV electron beams for two different field sizes: 4×4 and 10×10 cm^2 at different SSDs. The changes in depth dose with field size and SSD are more pronounced for the higher energy beams than the low energies, very similar to the data presented by Saw et al. [1, 6, 7] for a similar machine. There are some subtle changes in the depth dose characteristics which are noticed in this study. The changes in depth dose with field size are much smaller for 6 MeV than for 20 MeV. For example, at

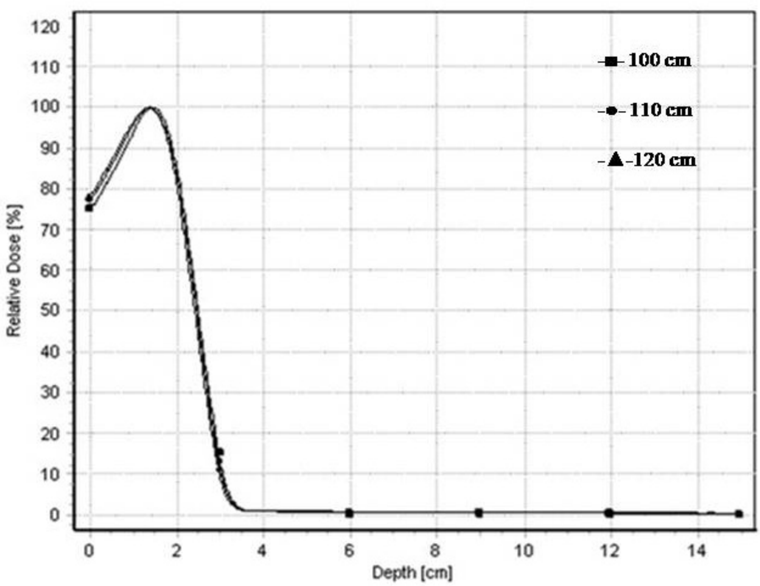

Figure 1a. Depth dose curves at various SSDs for 6 MeV beam for 4×4 cm^2 field size

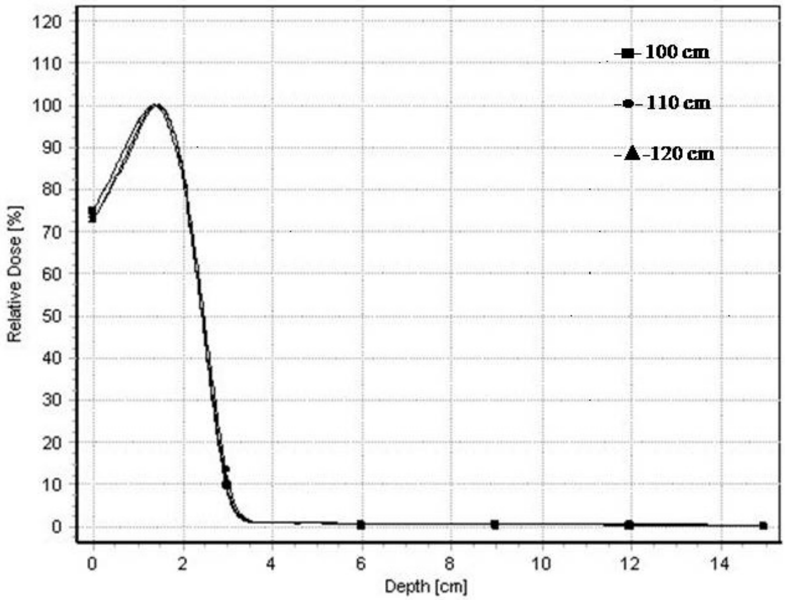

Figure 1b. Depth dose curves at various SSDs for 6 MeV beam for 10×10 cm^2 field size

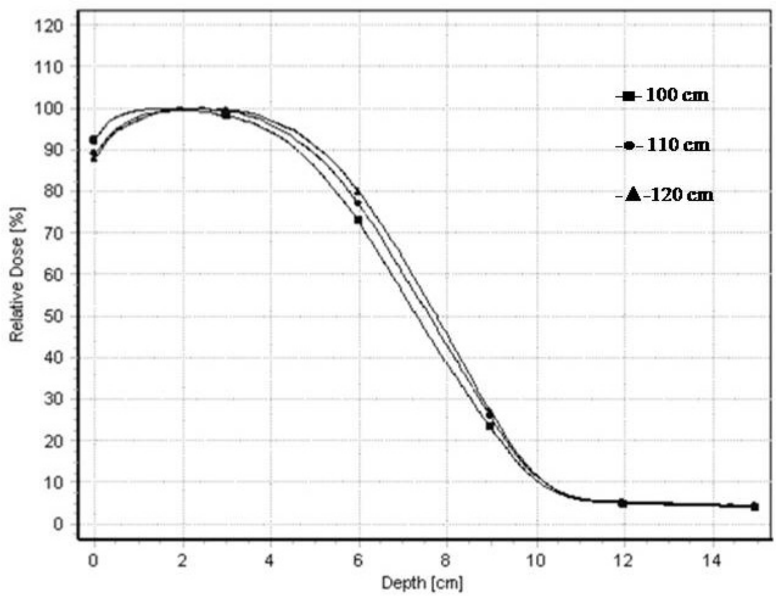

Figure 1c. Depth dose curves at various SSDs for 20 MeV beam for 4×4 cm^2 field size

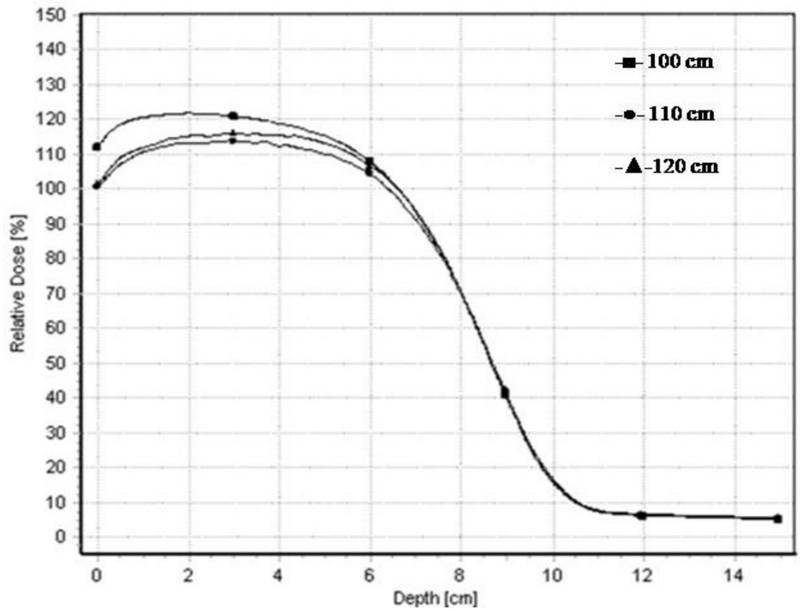

Figure 1d. Depth dose curves at various SSDs for 20 MeV beam for 10×10 cm^2 field size

100 cm SSD the depths of the 90% isodose lines for 20 MeV are 4.6 and 5.8 cm for field sizes of 4×4 cm^2 and 10×10 cm^2 respectively, and for 6 MeV, these are 1.9 and 1.8 cm. Similarly the change in depth dose with SSD was more pronounced for 20 MeV than for 6 MeV for small field size. On the other hand, the changes in surface dose with SSD and field size are less dramatic. The surface dose decreases as the SSD was increased for all fields and beam energies. The difference in surface dose was about 4-8% for both field sizes and beam energies. Table 1a and 1b shows the values of depth of maximum dose (R_{100}), relative surface dose and bremsstrahlung component at various SSDs for 6 and 20 MeV for 10×10 cm^2 field size. The changes in d_{max} for small field size (4×4 cm^2) with varying SSDs and beam energies are relatively small. For large fields ($\geq10\times10$ cm^2) d_{max} is constant up to 12 MeV. For higher energy beams ($\geq$ 12 MeV), d_{max} increases with SSD. However it is unimportant due to the broad spectrum of the depth dose curve. The changes are significant ($\leq$ 10%) in the buildup region for all energies and field sizes at longer SSDs. The bremsstrahlung component increased with beam energy and there was no significant variation with the increase in SSD.

Table 1a. Characteristics of 6 MeV electron beam for 10×10 cm² at extended SSDs

SSD	R_{100}	D_s [%]	D_X [%]
100	1.33	76.2	0.3
102	1.41	75.2	0.3
104	1.39	75.1	0.3
106	1.39	75.0	0.3
108	1.43	74.5	0.3
110	1.43	74.2	0.3
115	1.41	74.1	0.3
120	1.41	73.9	0.3

Table 1b. Characteristics of 20 MeV electron beam for 10×10 cm² at extended SSDs

SSD	R_{100}	D_s [%]	D_X [%]
100	1.97	92.8	4.6
102	2.35	91.8	4.7
104	2.49	91.2	4.8
106	2.69	90.7	4.8
108	2.67	89.9	4.9
110	2.89	89.2	4.9
115	3.19	89.0	5.0
120	2.93	88.0	5.1

Figures 2a and 2b show the beam profiles for 4×4 and 10×10 cm^2 fields at 100, 110 and 120 cm SSD for a 6 MeV beam at the respective $d_{\max}$. The loss of beam flatness was visible in the large SSD curves. The sharpness in the beam flatness was significantly reduced at large SSD. For smaller fields, the beam profile tends towards a Gaussian distribution for all energies. It was also noted that the width of the 50% isodose line, which is a measure of the radiation and light field at the standard SSD, differs significantly for 100-120 cm SSDs. It suggests that at a larger SSD the 50% isodose line

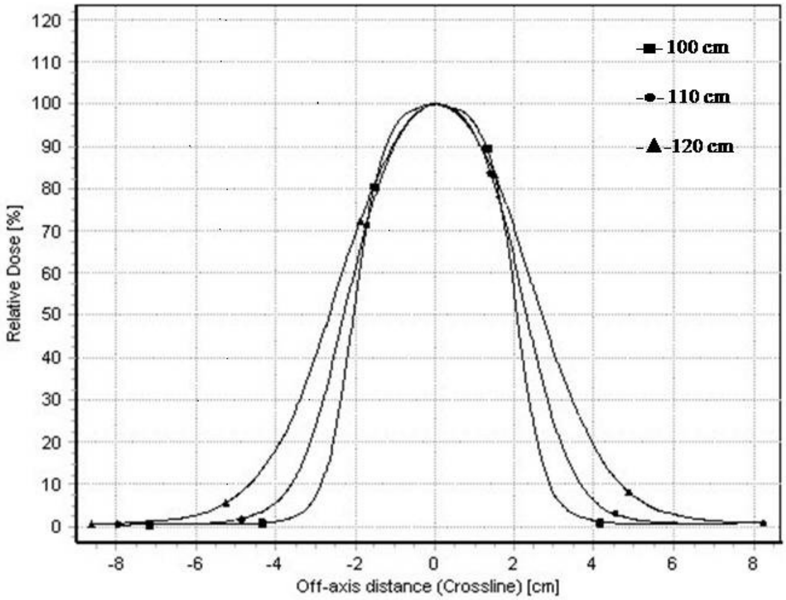

Figure 2a. Dose profiles for a 6 MeV beam at 100 cm, 110 cm and 120 cm SSD for 4×4 cm^2 field size

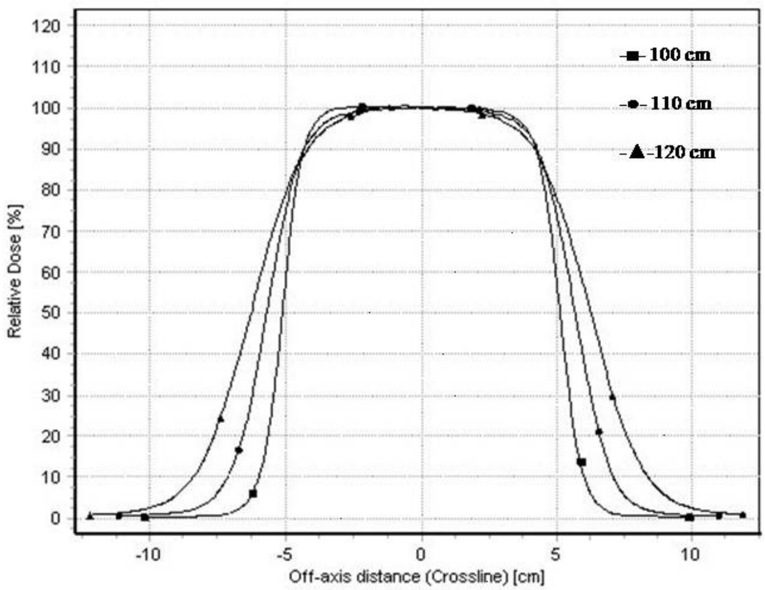

Figure 2b. Dose profiles for a 6 MeV beam at 100 cm, 110 cm and 120 cm SSD for 10×10 cm^2 field size

Table 2a. Flatness and symmetry for 4×4cm^2 and 10×10 cm^2 field size for 6 MeV at various SSDs

SSD	4×4 cm^2			10×10 cm^2		
	symmetry [%]	flatness [cm]	penumbra [cm]	symmetry [%]	flatness [cm]	penumbra [cm]
100	100.2	0.79	1.10	1.13	101.2	0.83
104	100.1	0.93	1.28	1.24	100.4	0.88
108	100.4	1.05	1.55	1.50	100.7	1.10
110	100.1	1.16	1.69	1.63	100.4	1.21
115	100.0	1.28	2.01	1.97	100.3	1.52
120	100.0	1.32	2.33	2.31	100.5	1.81

Table 2b. Flatness and symmetry for 4×4cm^2 and 10×10 cm^2 field size for 20 MeV at various SSDs

SSD	4×4 cm^2			10×10 cm^2		
	symmetry [%]	flatness [cm]	penumbra [cm]	symmetry [%]	flatness [cm]	penumbra [cm]
100	100.1	0.28	0.45	0.44	101.7	0.36
104	100.2	0.37	0.60	0.58	100.5	0.37
108	100.6	0.45	0.75	0.73	110.4	0.46
110	101.0	0.48	0.77	0.75	100.7	0.53
115	100.4	0.59	0.94	0.93	100.4	0.68
120	100.4	0.69	1.07	1.07	101.0	0.70

definition for field size could not be used. Table 2a and 2b shows the flatness, symmetry and penumbra values for 6 and 20 MeV electron beam for 4×4 cm^2 and 10×10 cm^2 field size at various SSDs. The flatness and symmetry were evaluated based on international electro technical commission (IEC) [4] specification. The beam flatness requires that the maximum distance between the 90% dose and the edges of the geometrical field shall be < 10 mm along the principle axis. The symmetry of the beam measured by the difference

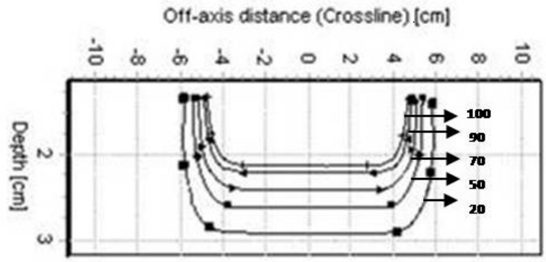

Figure 3a. Isodose distribution of 6 MeV electron beam with 10×10 cm^2 field size at 100 cm SSD

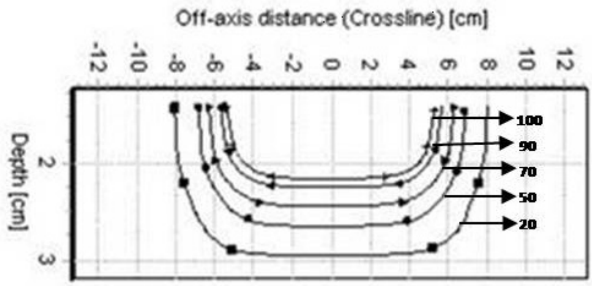

Figure 3b. Isodose distribution of 6 MeV electron beam with 10×10 cm^2 field size at 120 cm SSD

in dose at two points symmetrically placed to the central axis. Beam symmetry was within limit at extended SSDs for all the energies and field sizes. For smaller field size the flatness was better when compared to larger field size and it was poorer as the distance increased. For higher energies the flatness was within limit. Radiation penumbra increased with increase in SSD. Figures 3a and 3b show the isodose distribution for 6 MeV electron beam for 10×10 cm^2 field size at 100 cm and 120 cm SSDs. As seen in the figures, the electron field penumbra enlarges at extended SSD. The enlargement of penumbra implies an increase in the treatment volume. In addition to the penumbra, the dose distributions also show the loss of electron beam flatness characterized by a round shape profile at the depth of measurement, in particular at maximum dose depth at extended SSDs.

Figures 4a and 4b show the isodose perpendicular to the central plane for 6 MeV beam for 4×4 cm^2 fied size at 100 cm and 120 cm SSD. From the isodose the uniformity index (UI) [1, 3] was calculated. The uniformity index is defined as the ratio of area inside

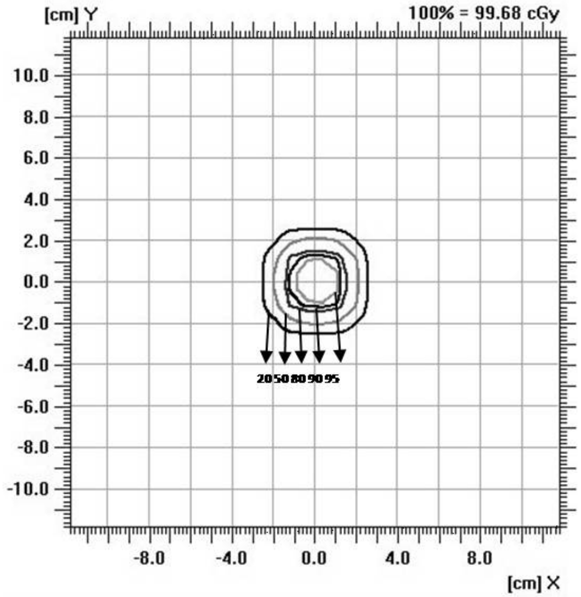

Figure 4a. Isodose perpendicular to the central plane for 6 MeV for 4×4 cm^2 field size at 100 cm SSD

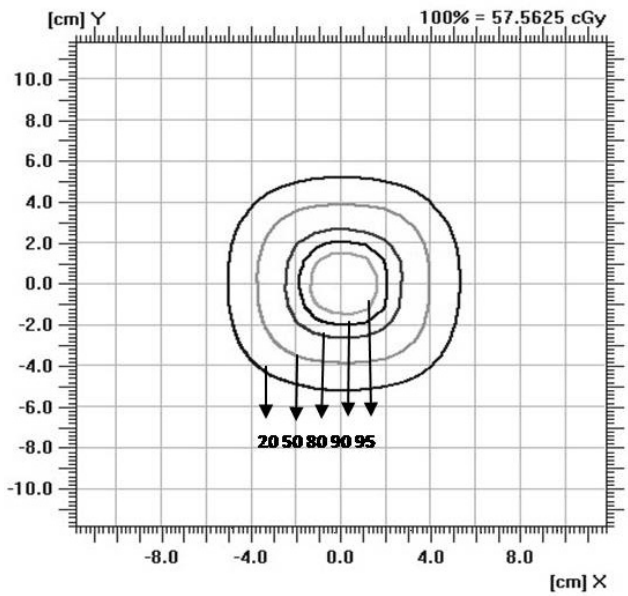

Figure 4b. Isodose perpendicular to the central plane for 6 MeV for 4×4 cm^2 field size at 120 cm SSD

Table 3. Uniformity index for five electron energies at various SSDs for different field sizes.

SSD	6 MeV			9 MeV			12 MeV			16 MeV			20 MeV		
	4×4 [cm]	10×10 [cm]	15×15 [cm]	4×4 [cm]	10×10 [cm]	15×15 [cm]	4×4 [cm]	10×10 [cm]	15×15 [cm]	4×4 [cm]	10×10 [cm]	15×15 [cm]	4×4 [cm]	10×10 [cm]	15×15 [cm]
100	0.37	0.66	0.73	0.39	0.69	0.79	0.42	0.68	0.77	0.43	0.69	0.79	0.43	0.68	0.79
104	0.45	0.64	0.71	0.49	0.68	0.79	0.57	0.67	0.78	0.61	0.68	0.79	0.64	0.68	0.78
108	0.38	0.59	0.68	0.46	0.65	0.76	0.54	0.66	0.76	0.60	0.68	0.78	0.61	0.68	0.76
110	0.37	0.56	0.65	0.43	0.63	0.75	0.50	0.64	0.74	0.56	0.68	0.76	0.59	0.68	0.76
115	0.3	0.49	0.61	0.38	0.59	0.70	0.49	0.63	0.71	0.54	0.68	0.76	0.57	0.68	0.75
120	0.26	0.44	0.56	0.35	0.54	0.67	0.42	0.60	0.69	0.50	0.65	0.73	0.53	0.68	0.73

90% and 50% isodose line. The UI values are given in Table 3 for 6, 9, 12, 16 and 20 MeV beam for various field sizes at various SSDs. The uniformity index increased with increasing the beam energy and field size. The uniformity index reduced significantly as the distance increased for 6 MeV and 9 MeV beams and far smaller fields. For higher energies there was not much change in the uniformity index as the distance increases. An acceptable lower limit of 0.7 for the uniformity index has been suggested for the therapeutic electron beams with field sizes larger than 10×10 cm [3]. For 6, 9, 12, 16 and 20 MeV energies the reduction in the uniformity index for a 10×10 cm^2 field size were 33%, 22%, 11%, 6% and 0%, when compared with nominal 100 cm SSD.

Discussion

The reduction in surface dose with increase in SSD may be due to elimination of low energy electrons from the beam air column and also by the change of scattered dose component from the electron beam flattening system reaching the point of measurement. The decrease in surface dose is complemented by the change in depth of maximum dose, d_{max} towards greater depth. Extended SSD does not affect the depth dose curves of higher energy electron beams with small cone size. The ICRU Report No. 35 [3] states that the change in the shape of the depth dose curve with SSD is determined mainly by the geometric divergence of the beam. The application of the inverse square law, using the effective SSD, brings the depth versus absorbed dose curves obtained at different SSD in to close agreement. The loss of beam uniformity for small fields and large SSDs is due to multiple scattering of the electron beam. For high energies where the scattering power of the electron beam is lower and the beam is more forwardly directed, the beam spread is relatively small. The beam uniformity can be slightly increased by using a tertiary collimator at the skin. For smaller fields the beam broadens significantly compared to the larger fields. The clinically useful isodose level (80% and 90%) width decreases linearly wit the SSD. It suggests that the target coverage at an extended SSD may be inadequate unless relatively larger fields are used. On the contrary, the widths of 50% and 20% lines increase steadily with SSD. The increase in the width of the 50% line suggests that the definition of radiation field width at extended distances cannot be used due to a significant increase in radiation field size. The increase in penumbra at extended SSD could be attributed due to the larger angular scattering of electrons. The enlargement of penumbra implies an increase in the treatment volume.

Conclusion

Even though the effects of extended SSD on the electron beam depth dose curves have been studied by several investigators, the results are not conclusive [1, 2, 6, 7]. This study shows that the extended SSD does not cause a dramatic change on the depth dose curves. The study also shows that the extended SSD effect on the rapid dose fall of region depends on the cone size used. For clinical situations at extended treatment distance, the field size should be enlarged for adequate lateral coverage. In general electron beam characteristics at extended distances are dependant on the machine design and type of collimation. Dosimerty has to be performed before the treating the patients at extended SSDs.

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