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DOSE MEASUREMENT UNDER THE SHIELDED AREA IN ELECTRON BEAM RADIOTHERAPY - A PHANTOM STUDY

Oncology

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ABSTRACT

Background: Electron beam therapy is used to treat superficial tumors. Cerrobend cutout is used to shape the electron beam to conform to the target area. If the dose below the cut-out is higher than planned, it can lead to increased radiation exposure to nearby organs at risk (OARs). The purpose of this study is to measure the surface dose below the electron cut-out for clinically significant electron energies and applicators. **Materials and Methods:** 2 cm thick Cerrobend alloy (50% bismuth, 26.7% lead, 13.3% tin, and 10% cadmium) cutouts of specific dimensions were made, and the dose below the cutout was measured in the Varian Truebeam (V3.0) linear accelerator for electron energies of 9, 12, and 15 MeVs and various applicators (10x10, 15x15, 20x20, and 25 x 25 cm²). Measurements were done in the RW3 Slab phantom using the FC65G Farmer Chamber connected to the IBA-dose 1 electrometer. The charge collected in the electrometer was converted into dose by applying correction factors and compared with the dose estimated by the Eclipse (V17.0) treatment planning system. **Results:** The percentage deviation between TPS-calculated and measured values of surface dose below the cut-out was 4.25%, -57.99%, -28.08%, and -54.35% for 10x10, 15x15, 20x20, and 25x25 cm^2 applicators, respectively, for 9 MeV. For 12 MeV: 16.29%, -50.37%, 0.76, and -31.44 for 10x10, 15x15, 20x20, and 25x25 cm^2 applicators, respectively. For 15 MeV: -8.77%, -2.8%, 10.54%, and -23.33% for 10x10, 15x15, 20x20, and 25x25 cm^2 applicators, respectively. **Conclusion:** This study suggests adapting pre-treatment surface dose evaluation as a regular practice for electron beam treatments using customized blocks. This will give better confidence in dose protection to organs at risk below the custom block while ensuring the maximum dose to the tumor.

KEYWORDS

Radiation, Radiotherapy, Quality assurance, Electron beam therapy, Cerrobend blocks

INTRODUCTION

Radiation therapy treatment uses various types treatment beam to eliminate the cancerous cells. Two major type of treatment beams that are commonly used during the radiation therapy treatment are photons; also known as x-rays and electrons [1]. Electron beam radiotherapy is particularly effective for treating superficial tumors due to its unique dose distribution, which delivers high doses at shallow depths followed by a rapid dose falloff. This capability minimizes the risk of radiation damage to deeper tissues, making electron beams an essential tool in modern cancer treatment.

The most clinically useful energy range for electrons is 6 to 20 MeV. At these energies, the electron beams can be used for treating superficial tumors (<5 cm deep) with a characteristically sharp drop-off in dose beyond the tumor. The principal applications are (a) the treatment of skin and lip cancers, (b) chest wall irradiation for breast cancer, (c) administering boost dose to nodes, and (d) the treatment of head and neck cancers [2].

Electron therapy treatments commonly employ patient-specific devices to shape the lateral beam edges according to the physician's defined treatment volume. A lead or metal alloy cut-out is crafted and positioned on the applicator, placed as close to the patient as possible to achieve a more customized field shape. The most common system for customized beam shaping commonly used is called Cerrobend [3]. If the dose below the cut-out is higher than planned dose, it can lead to increased radiation exposure to nearby organs at risk (OARs). Therefore it is essential to measure the dose received to the area under the electron cut-out.

Task Group 25 considers a transmitted dose under the block value of not more than 10% in most clinical cases to be acceptable [4]. Numerous studies have explored the impact of shielding material thickness on electron beam transmission and the effects of various shielding materials on beam attenuation [5 - 8]. Building on this foundation, our study focuses on measuring the dose delivered beneath the electron cutout and comparing these measurements with the dose values calculated by the treatment planning system (TPS). This comparison aims to evaluate the accuracy and reliability of TPS dose calculations in the presence of shielding materials.

MATERIALS & METHODS

In this study, 2 cm thick Cerrobend alloy cut-outs, composed of 50% bismuth, 26.7% lead, 13.3% tin, and 10% cadmium, were prepared with specific dimensions to suit various applicator sizes (fig.1).

Figure 1: Dimensions of Cerrobend Blocks Used for the Measurements

The cut-out openings measured 5 cm x 8 cm for a 10 cm x 10 cm applicator, 5 cm x 12 cm for a 15 cm x 15 cm applicator, 5 cm x 17 cm for a 20 cm x 20 cm applicator, and 5 cm x 22 cm for a 25 cm x 25 cm applicator. A treatment plan was created using a scanned phantom in the Varian (A Siemens Healthineers Company) Eclipse treatment planning system (V17.0) for a prescribed dose of 200 cGy; with dose calculations performed using the electron Monte Carlo algorithm. The dose beneath the cutout was measured on a Varian (A Siemens Healthineers Company) Truebeam (V3.0) linear accelerator for electron energies of 9 MeV, 12 MeV, and 15 MeV, using various applicators.

The RW3 slab phantom (IBA Dosimetry) was aligned with the crosshairs, and an FC65G Farmer chamber (IBA Dosimetry) was

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inserted into the adapter plate slot (fig. 2). The treatment couch was then laterally shifted by 3 cm to position the chamber near the field border, ensuring it was not too far from the border (fig 3). This lateral shift was done to keep the chamber in a region where the dose gradient was expected, as opposed to being directly at the central axis.

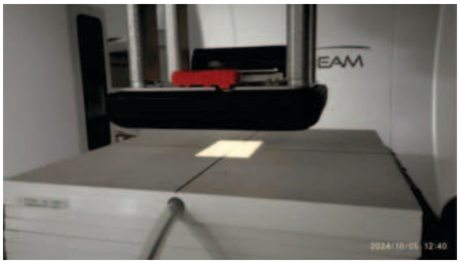

Figure 2: Alignment of the Phantom Before Moving the Table Laterally

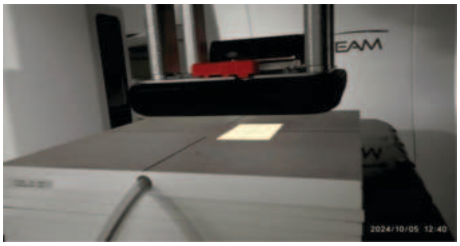

Figure 3: Alignment of the Phantom After Moving the Table 3cm Laterally From the Isocentre

The chamber was connected to Dose 1 electrometer (IBA Dosimetry), which recorded the charge. Later the charge collected was converted into dose. The dose predicted by the Eclipse TPS was noted at a point 1 cm below the surface of the phantom and 3 cm laterally from thecentral axis. Finally, the measured dose and TPS-estimated dose were compared, and the percentage deviation was calculated to evaluate the accuracy of the TPS predictions.

RESULTS

The results of the study are presented in Table 1, Table 2, Table 3, Table 4, Figure 4, Figure 5, and Figure 6.

The charge collected for all energy and applicator combinations was recorded and converted into dose using the Nd,w factor and correction factors, as per the formula:
Dose (Gy) = Meter reading (nC) * Correction factors * Nd,w(Gy/C), following the TRS 398 protocol. The polarity correction factor and electrometer correction factor were taken as unity. The results are summarized in Tables 1, 2, and 3

Table1: Charge Collected for 9 Mev Electron Energy Using Different Applicators

9MeV		
Applicator size (cm x cm)	Meter reading (nC)	Dose (Gy)
10 x 10	3.433	0.1574
15 x 15	1.778	0.0815
20 x 20	3.184	0.146
25 x 25	2.838	0.1301

Table2: Charge Collected for 12 Mev Electron Energy Using Different Applicators

12MeV		
Applicator size (cm x cm)	Meter reading (nC)	Dose (Gy)
10 x 10	2.689	0.1221
15 x 15	1.781	0.0809
20 x 20	2.993	0.1328
25 x 25	2.733	0.1241

Table3: Charge Collected for 15 Mev Electron Energy Using Different Applicators

15MeV		
Applicator size (cm x cm)	Meter reading (nC)	Dose(Gy)
10 x 10	2.949	0.1332
15 x 15	2.604	0.1176
20 x 20	3.327	0.1503
25 x 25	3.107	0.1403

From Table 4, it is observed that the dose predicted by the TPS under the cut-out ranges from 5% to 14% of the maximum dose, while the actual dose measured under the cut-out varies between 4% and 7% of the maximum dose.

Table 4: Percentage Deviation Between TPS Calculated and Measured Dose

Energy (MeV)	Applicator Size (cm x cm)	TPS Calculated Dose(Gy)	Measured Dose(Gy)	Percentage Deviation
9	10x10	0.151	0.157	4.24
	15x15	0.194	0.081	-57.99
	20x20	0.203	0.146	-28.08
	25x25	0.285	0.081	-54.35
12	10x10	0.105	0.122	16.29
	15x15	0.134	0.081	-50.37
	20x20	0.131	0.133	0.76
	25x25	0.181	0.124	-31.44
15	10x10	0.146	0.133	-8.77
	15x15	0.121	0.118	-2.8
	20x20	0.168	0.15	10.54
	25x25	0.183	0.14	-23.33

The percentage deviation between the TPS-calculated and measured surface dose below the cut- out varied as follows: for 9 MeV, the deviations were 4.25%, -57.99%, -28.08%, and -54.35% for the 10 x 10, 15 x 15, 20 x 20, and 25 x 25 cm^2 applicators, respectively. For 12 MeV, the deviations were 16.29%, -50.37%, 0.76%, and -31.44%, while for 15 MeV, the deviations were - 8.77%, -2.8%, 10.54%, and - 23.33% for the same applicator sizes.

Figure 4 shows that the difference between measured and calculated doses was smaller for the 10 x 10 cm^2 applicator, with the discrepancy increasing as the applicator size grew.

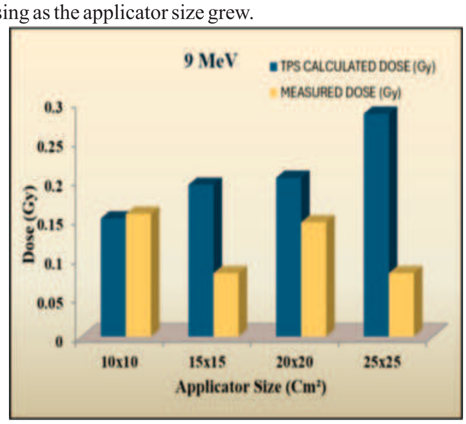

Figure 4: Comparison of percentage deviation between TPS calculated and measured dose for 9 MeV

Figure 5 highlights that the TPS overestimates the dose for larger applicators, with deviations being more prominent for the 15 x 15 cm^2 and 25 x 25 cm^2 applicators. Conversely, the agreement is closer for the 10 x 10 cm^2 and 20 x 20 cm^2 applicators.

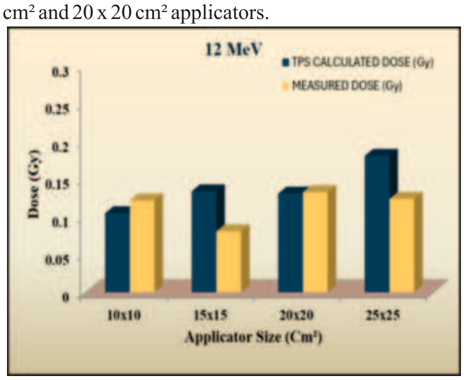

Figure 5: Comparison of percentage deviation between TPS calculated and measured dose for 12 MeV

Figure 6 suggests that the TPS-calculated dose aligns closely with the measured dose for smaller applicators, but the deviation grows as the applicator size increases, particularly for the largest size (25 x 25 cm²), where the TPS overestimates the dose.

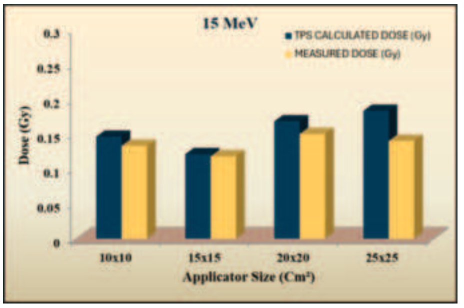

Figure 6: Comparison of percentage deviation between TPS calculated and measured dose for 15MeV

DISCUSSION

Table 1 indicates that in most energy and applicator combinations, the TPS predicts a higher dose than what is delivered. Deviations were observed between the TPS-calculated dose and the measured dose, with significant differences. These discrepancies can likely be attributed to variations in the thickness of the Cerrobend material used during actual measurements compared to the assumptions made in the TPS dose calculation. The larger deviations observed indicate that the exact dose received under the shielded area was considerably lower than the dose predicted by the TPS. This suggests that inaccuracies in modelling the shielding material's thickness and distribution within the TPS could lead to overestimated dose predictions, emphasizing the importance of more precise modelling to improve the accuracy of dose calculations.

The results showed no particular trend in dose under the cutout with the increase in energy or applicator size in both TPS calculations and actual measurement. This randomness in the measured dose could be attributed to inhomogeneity and irregularities in the Cerrobend cut-out due to impurities and air bubbles. A. Tahekhani et al. [9] reported in his study that an air bubble with a diameter larger than 3 mm could affect beam attenuation significantly. The exactlocation of the point of interest in the treatment plan was not reproducible for all the energy and applicator combinations in TPS using the point dose measurement tool.

Hideo Kubo et al [10] in his study reported that a significant amount of dose exists under a cutout, requiring detailed evaluation. For 20 MeV electron beams, the dose under the cutout varied up to 10% of the maximum dose along the central axis. In the present study, the maximum dose measured under the cut-out was 7% for 9Mev with a 20x20 cm2 applicator. Regarding 6 MeV electron beams, it was observed that the dose near the field edge under the cutout was comparable to that of 20 MeV electrons but decreased rapidly with increasing cutout-to-field distance (CFD). The findings attributed these doses mainly to electron scattering near the edges of the low-energy electron field and bremsstrahlung x-rays generated beneath the cutout. These observations emphasize the importance of considering these dose contributions during treatment planning to ensure precise dose delivery.

Sonja Petkovska et al [11] in his study measured the PDD for open and block fields for all electron energies and compared them. It was reported that the maximum dose under the blocked electron beam occurs on the central axis closer to the surface. This result is similar to the findings of Jadwiga B. Wojcicka et al [12]. Based on the above two studies, a limitation of our study is that the dose was measured at a depth of 1 cm from the surface. In this study, the dose measurements were performed, focusing on a point 3 cm laterally from the central axis. In certain practical scenarios, such as the treatment of nose cancers, the lens, an important critical organ is positioned approximately at that distance. From the results of this study, it can be ensured that the actual dose at that point is lower than the value predicted by the TPS.

The accuracy of implementation of the electron Monte Carlo algorithm in Eclipse TPS was studied by several groups [13- 16] and reported that the Monte Carlo algorithm for electron planning in Eclipse is more accurate than previous algorithms. The results of this study show an overestimation of dose in algorithm-based calculations.

CONCLUSIONS

This study highlights the significant deviations observed between TPS-calculated dose and measured dose under shielded areas during electron beam treatments. The discrepancies can be attributed to differences in the thickness of the Cerrobend material used in actual measurements compared to the assumptions made during TPS dose calculations. Larger deviations were observed in most cases, with the TPS overestimating the dose received under the shielded area.

Based on these findings, this study suggests adopting pre-treatment surface dose evaluations as a routine practice for electron beam treatments involving customized blocks. This practice would ensure greater accuracy in dose delivery and provide better confidence in protecting organs at risk located beneath the shielded areas.

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