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Factors impacting the dose at maximum depth dose (dmax) for 6 MV high-energy photon beams using different dosimetric detectors

Objectives: Deciding the tumorcidal dose is very important in radiation therapy as it is limited by skin dose. The aims of this **study** were to investigate the impacts of using physical wedge filter, different source to surface distances (SSD) and field sizes (FS) on the dose at the depth of maximum dose (dmax) using 6 MV high-energy photon beams.
Materials and methods: The measurements were made in Solid Water Phantom at different settings of SSD and FS for 6 MV high-energy photon beams using LiF: Mg; Ti TLD and FC65-G Ionization Chamber.
Results: It was observed that when physical wedge was used at reference settings, the doses at dmax decreased significantly as compared with open fields. Moreover, these doses decreased proportionally with an increase in the wedge angle until 45°, after which the dose increased slightly. The doses at dmax were also inversely related to SSD while it had an extrusive relationship with field size.
Conclusion: This study shows that for high energy photon beams the doses at dmax are affected by the use of wedge filter, SSD and FS as confirmed by two different detectors. Consequently, choosing the appropriate settings to achieve the desired dose at dmax should be considered in clinical use.

Key words: Thermoluminescent dosimeter, Wedge factor, Maximum depth dose

INTRODUCTION

Radiotherapy treatment by high energy photon beams requires careful consideration as it produces inhomogeneous doses in the surface region which in turn cause damage to the skin and normal tissue that is attributed to skin-sparing effect {1, 2}. The use of physical wedge filters absorbs low-energy scattered electrons {3} and produces lower surface doses and a higher skin-sparing effects thus decreasing skin damage {4}. On the other hand, ensuring a desired clinical outcome and the efficacy of radiotherapy treatment is another research concern that needs further investigation to explore the impact of using physical wedge at the maximum depth dose as well as for other setting conditions.

As the electron or photon beam is incident, the absorbed dose in the patient or phantom varies with depth and depends on energy, depth, field size (FS), source to surface distances (SSD), and beam collimation system. The calculation of dose in the patient affects depth dose distribution with regard to these parameters {5-9}. As it is difficult to measure the percentage depth dose (PDD) specially at the depth of maximum dose (dmax) correctly by using Ion Chamber due to its size, a small dosimeter (extrapolation chamber, parallel chamber, thermoluminescent dosimeters (TLDs), MOSFET) should be used for high-energy photon beam {10, 11}. TLDs are used in a variety of medical applications including radiation therapy, diagnostic radiology, and radiotherapy mailed dosimetry, particularly the LiF:Mg,Ti TLD type which has been the most dominant in the field of TL medical dosimetry {12}.

The aims of this study were to investigate the effect of using physical wedge filter, SSD, and FS on the dose at the depth of maximum dose (dmax) on Solid Water Phantom and to determine precisely the percentage dose at different depths using TLDs and Ionization Chamber for 6MV high energy photon beam.

MATERIALS AND METHODS

The TLDs used in this study were selected from a batch of LiF:Mg;Ti square chip having dimensions of 3.00 x 3.00 x 0.89 mm^3 as obtained from the manufacturers (Bicron NE, USA) and the Ionization Chamber used was Fc65-G (Willower, Germany). Siemens Mevatron MD2 LINAC (Siemens Inc, USA) was the radiation source in this study.

Since TLDs, as dosimeters, can be reused for hundreds of times, annealing treatment should be done prior to each irradiation. This is required especially in medical therapy applications, where high doses are the norm and the highest accuracy is desired, otherwise annealing is usually omitted {13, 14}. In the present study, LiF:Mg;Ti TLDs were annealed for 1 h at 400 °C to remove the residual charges in the competitors thereby avoiding sensitization, followed by rapid cooling. Afterward, they were treated for 24 h at 80 °C to associate the dipoles into trimmers, thus removing low temperature TL peaks and reducing fading when integrating intensity measurements {13, 15}. A Nabertherm oven (Nabertherm, Germany) was used to anneal the TLDs and a Harshaw model 3500 (Harshaw, USA) was used as the TLD reader. The TLDs were selected after a careful initialization procedure {16}. The reading profile was as follows: Preheat temperature of 50 ºC for 0 sec, acquire temperature rate 12 ºC/sec, acquire maximum temperature of 300 ºC for 33 sec , and annealing temperature of 300 ºC for 0 sec. The TLDs were selected for the sensitivity within 5 %.

As it was difficult to make holes in Solid Water Phantom to place the TLDs, a number of 4 mm thick slabs of Perspex phantom were fabricated with holes within the surface having a diameter of 4.5 mm. TLDs were then placed in them for calibration and dose measurement purposes. The holes are about 1cm apart in order to avoid any influence on dose because of the slightly higher density of TLDs (2.64 gm/cm^3) {17}. The slabs were inserted in between the Solid Water Phantom (Nuclear Associates, Chicago, IL) at d_{max}. 6 MV beams from a Siemens Mevatron MX2 linear accelerator (Siemens Inc, USA) with dual energy photon and electron beams used to irradiate TLDs at a nominal SSD of 100 cm with a (10 x 10 cm^2) field size. For calibration purposes, a dose of 100 cGy was delivered from the 6 MV photon beams. A FC65-G (Wellhofer, Germany) ionization chamber was used for the TLD calibration. Ten subsequent calibration cycles were carried out to establish individual calibration factors as well as elemental correction coefficients (ECC) and common calibration factors as alternatives. Separate calibration of field size, angle, wedge, dose rate dependence, and linearity correction were done for the TLDs.

A few TLDs were separated into subgroups, which were used as control. Although common and individual calibration is established for all dosimeters, these controls were irradiated to a known dose at the same time as a measurement run and read out along with the TLD measurements to rule out any uncertainties in TLD calibration. The accuracy of TLD measurements depends on the reproducibility of the result {15, 16, 18, 19} as measured by the standard deviation of each individual calibration factor. The individual backgrounds for each TLD were not subtracted from the gross readings since the background was so low compared with the TL of 100 cGy (less than 0.01 % for LiF:Mg,Ti).

The Calibration setup is presented in Figure 1. A fullback scatter was applied during calibration and for subsequent experiments. The dose from 25 cGy to 400 cGy from a linear accelerator beam was measured to find out any variation in linearity of dose for those beams. Non–reference conditions including variations in field size and SSD were also studied. The effect of standard wedges (30º, 45º and 60º) on the TLD signal was examined and a PDD curve was determined.

RESULTS

Linearity Response

For different dose values using 6 MV X-rays, the response TLD curve as a function of dose ranging between 25 to 400 cGy was linear (Figure 2). A 100 cm SSD, 10 cm thickness of Solid Water Phantom for back scattered, and 10 x 10 cm^2 field sizes were fixed during linearity response study.

Field Size Response

Field size dependence was performed by exposing the TLDs and Ion Chamber to different field sizes (ranged from 5 x 5 cm^2 to 20 x 20 cm^2) and reference settings. It was found that the dose at the depth of maximum dose (1.5 cm) increased nearly linearly with the field size (Figure 3 and Table I).

Source Surface Distance (SSD)

With regard to SSD dependence, TLDs were exposed to different SSD (ranged from 80 to 130 cm) and reference settings were used for all measurments. It is noticeable from Figure 4 that for 6 MV, the dose at d_{max} decreased nearly linearly with increasing SSD.

Determination of the Opening Collimator Factor (OCF)

Figure 5 shows the OCF factor for both TLDs and Ion Chamber for various field sizes. The OCF was determined as a ratio of measured dose at a given field size to the calculated dose at reference field size (10 x 10 cm^2) at d_{max}. Refering to Figure 5, the output factor increases with increasing field size for both TLDs and Ion Chamber. For the field size ranging from 5 x 5 to 20 x 20 cm^2, the maximum discrepancies between OCF measurements were 6 %; this appeared because TLDs and Ion Chamber have different energy responses.

Effect of Wedge

A Relative Wedge Factor (RWF) defined by normalizing the WF for a particular wedge and field size to 1.00 at the reference depth:

$$RWF(d,FS)=\frac{WF(d,FS)}{WF(d_{ref},FS)}=\frac{D^{w}(d,FS)/D^{w}(d_{ref},FS)}{D^{o}(d,FS)/D^{o}(d_{ref},FS)}=\frac{DD^{w}(d,FS)}{DD^{o}(d,FS)} \quad (1)$$

The ratio between the central axis depth doses normalized at d_{ref}, with and without wedge (DD^o and DD^w), is specific for each wedge. The wedge correction factor (CF_{Wedge}) is defined as the ratio between the wedge transmission factor (W. T. F) for a 10 x 10 cm^2 field size, measured with the ionization chamber placed at d_{max}, and the wedge transmission factor for the same field size, measured with the TLDs placed at the centre of the field at d_{max} in the phantom.

$$CF_{Wedge}=\frac{W.T.F_{IonChamber}}{W.T.F_{TLD}} \quad (2)$$

$$W.T.F = DD^{w} / DD \quad (3)$$

The wedge factor at the depth of maximum dose (d_{max}) for TLDs and Ion Chamber as a function of wedge angle at 100cm SSD for 6 MV high-energy photons are shown in Figure 6. The wedge factor at d_{max} decreased for both TLDs and Ion Chamber as the wedge angle increased up to 45, after that it slightly increased. The same trends were observed when the correction factors and the percentage dose of TLD with the wedge angle were studied (Table II).

Percentage Depth Dose Curve

PDD curve study was performed by exposing the TLDs and Ion Chamber at different depths (ranged from 0 to 20 cm) and 10 cm thickness as full backscatter in the Solid Water Phantom at reference settings. The PDD curves are presented in Figure 7, for the depth ranging from 1.5 to 19 cm, the maximum discrepancies between Ion Chamber and TLDs reading were 5 %, while the discrepancy was 37 % at the surface.

DISCUSSION

There are insufficient literatures about the subject of surface and build-up region dose for high energy photon beams's use and TLDs, hence verification of our results becomes difficult. In our study the percentage dose at the surface of 10 × 10 cm^2 field size with 6 MV photon beams were found to be 51.5 % and 33.4 %, respectively. In other studies that have investigated the percentage dose at the surface with the same settings using different models of radiochromic films, it was found to be at a maximum of 20.3% {4, 20}. The discrepancies between the measurements using TLDs, Ionization Chambers and radiochromic films may appear because of the differences in their energy responses.

The findings also showed that the dose at d_{max} had an extrusive relationship with field size; by increasing field size from 5 to 20 cm^2 the dose increased proportionally. Previous studies found that at the same set up the percentage dose at the surface increased nearly linearly with field size {3, 4} that referred to the electron scattering from flattening filter, monitor chambers, collimators and the air between collimators and the phantom {21-23}.

As expected, the dose at d_{max} was inversely related with the SSD. This may be explained as in Bilge H *et al*., study that revealed an inverse relationship between SSD and

percentage dose at the surface. There was a decrease in the number of electrons reaching the surface when the distance was increased as some of the electrons were absorbed and scattered because of the beam divergence {4}. Consequently, the dose at d_{max} decreased.
Previous studies found that surface and buildup doses of 45° physical wedged beams for field size 10x10 cm^2 and 6 MV energy were lower than those of open field {3, 4}. On the other hand, Ochran *et al.*, in 1992, found that the surface doses were higher for physical wedge field as compared to open field {24}. In our study, the dose at d_{max} was comprehensively studied and found to be lower for all physical wedge angle (30°, 45°, 60°) compared with that of open field. Furthermore, the dose at d_{max} decreased proportionally with increasing wedge angle and this should be considered when adjusting the wedge angle in clinical use. On the contrary, Bilge H *et al*., study showed that the dose at d_{max} did not change in open and wedged beams {4}.
Moreover, it was found that the percentage dose at d_{max} decreased as the wedge angle increased up to 45° then slightly increased at 60° at the same reference settings. This is because the thickness of 45° wedges is slightly greater compared to that of 60º wedges. Our finding is in agreement with Bilge H *et al*., study {4} but differs from the results of Cozzi A F *et al*. study at the same settings {25}. The variations in wedge factors with wedge angle also showed the same trend and this may arise from changes in beam transmission through the wedge.

CONCLUSION

This study not only shows that the doses at d_{max} for high energy photon beams decreased significantly by using the wedge filter but also shows that they were changed by different wedge angle as confirmed by two different detectors namely the Ion Chamber FC65-G and LiF:Mg;Ti TLDs. Consequently, choosing the appropriate condition to achieve the desired dose at d_{max} should be considered in clinical use.

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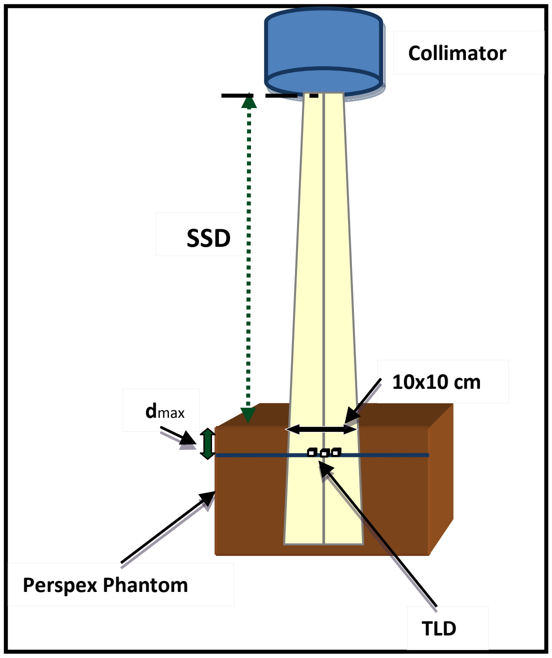

Figure 1: TLD calibration setup

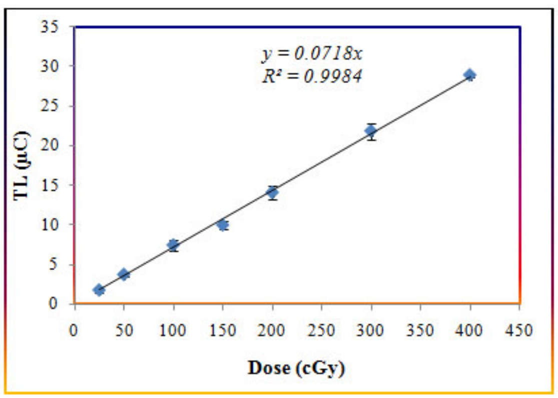

Figure 2: Linearity of TLD intensity against absorbed dose

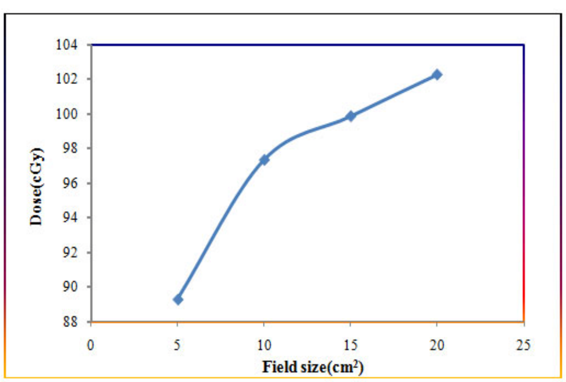

Figure 3: A dose at the d_{max} as a function of field size at 100 cm (SSD) for 6 MV photon beam

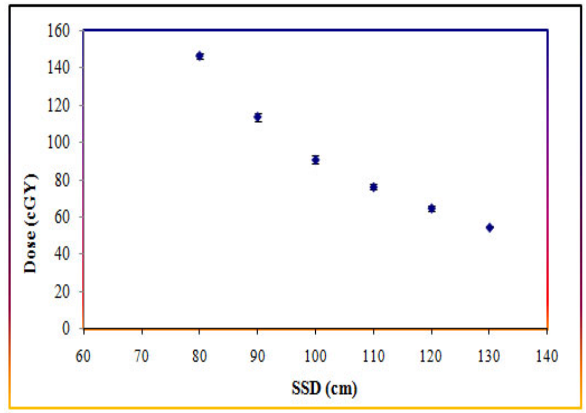

Figure 4: A dose at the depth of maximum dose as a function of source-surface distance (SSD) for 10x10 field size, 6MV high energy photon

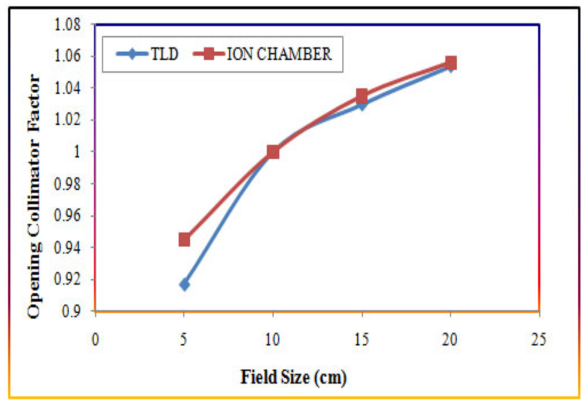

Figure 5: Output factor for TLD and ion chamber

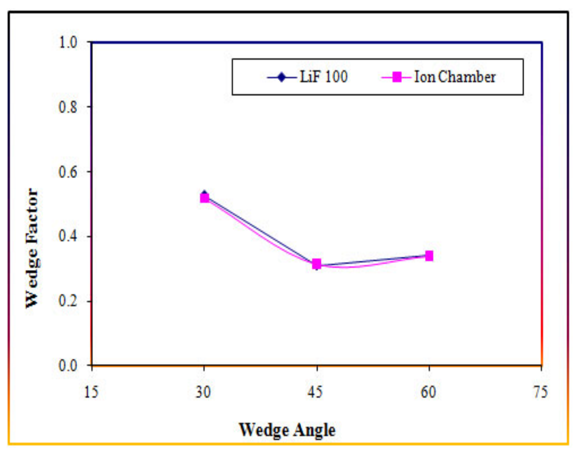

Figure 6: Wedge angle verses wedge factor for TLD and Ion Chamber

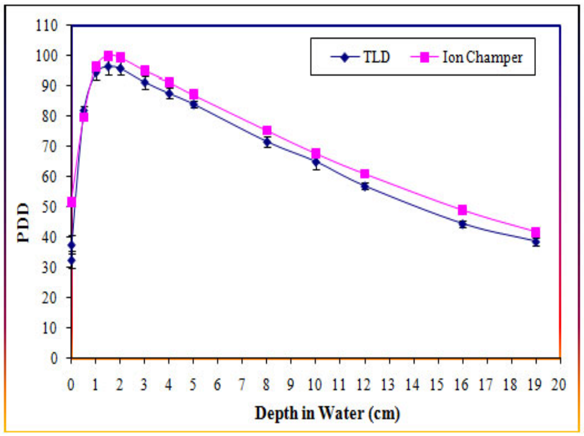

Figure 7: PDD curve in Solid Water Phantom for a 10 x 10 cm² field at an SSD of 100 cm for 6 MV photon beam using LiF 100 TLDs and ion chamber

Table I: Dose at the depth of maximum dose for 6 MV and for various field size at 100cm SSD

Field size (cm^2)	Average Dose (cGy)	Opening collimator factor	
		TLD	Ion chamber
5 x 5	89.3	0.917	0.945
10 x 10	97.49	1	1
15 x 15	99.9	1.026	1.035
20 x 20	102.27	1.051	1.056

Table II: Transmission Factor and Wedge Factor for both TLD and Ion Chamber Reading *(Mount Miriam Hospital)*.

Wedge angle	TLD reading		Ion Chamber Reading	
	Transmission Factor	Wedge Factor	Transmission Factor	Wedge Factor
30	2.184	0.458	1.93	0.518
45	3.821	0.262	3.20	0.316
60	3.203	0.312	2.94	0.340