Small beam dosimetry by using $\text{Al}_2\text{O}_3$ optically stimulated luminescent (OSL) dosimeters at high energy photons and electrons

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Abstract. The study focused on the measurements of depth dose for small beam in the high energy photons and electrons. The percentage depth dose (PDD) was measured in 6 and 10 MV photons and 9 and 12 MeV electrons at $3 \times 3$ cm field sizes by using the $\text{Al}_2\text{O}_3$ optically stimulated luminescent (OSL) dosimeters. The PDD in OSL dosimeters were compared to those in ionization chamber and Gafchromic EBT3 film dosimeter. The results showed that the PDD in OSL dosimeters in lower photon and electron energies were in good agreement within 4% to ionization chamber and film. The PDD in 10 MV photons however showed gradual increase of deviation up to 10% beyond the depth of maximum dose ($d_{\text{max}}$). The surface doses in OSL dosimeters were significantly higher compared to those in ionization chamber and film dosimeter. The overall results suggested the suitability of OSL dosimeters to be used as indirect dosimetry works in high energy photons and electrons.

1. Introduction

The use of small fields in radiotherapy helped in providing better accuracy of therapeutic beam deliveries. They usually having dimensions smaller than the lateral range of the charged particles that contribute to the dose deposited at a point along the central. The field sizes of less than $3 \times 3$ cm are considered to be small for photons beam [1]. It can be obtained by using multi leaf collimator (MLC) in typical linear accelerators. The MLC enable to conform with shape of target tumour and tailor to the prescribed dose distribution to the planning target volume (PTV). Not all dose distribution inside PTV or another volume are homogenous but heterogonous dose distribution are commonly occurred [2]. Therefore, the smaller and irregular collimator are required for complex dose distribution to ensure that the planned dose distributions are accurate throughout the define tumour volume. The small beam in radiotherapy is commonly applied in various treatment methods such as intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), stereotactic radiotherapy (SRT), stereotactic radiosurgery (SRS) and stereotactic ablative radiotherapy (SABR) [3]. The challenges in small field dosimetry includes lateral electronic disequilibrium, source occlusion, volume averaging effect and beam alignment [4-6]. Several dosimeters such as MOSFET, TLDs, ionization chambers as well as dose simulations by the treatment planning software (TPS) commonly used in radiotherapy.
The use of $\text{Al}_2\text{O}_3$ optically stimulated (OSL) dosimeters for dosimetry works in medical physics has been increasing in the recent years [7-9]. Previous works also indicated the suitability of OSL dosimeters for dosimetry works in the open fields of high energy photons and electrons [10,11]. The measurement of percentage depth dose (PDD) had been the most convenient method to evaluate the attenuation and dosimetric properties of dosimeters at the function of depth in clinical photons and electrons [12]. This study measured the PDD of small beams of photons and electrons by using the OSL dosimeter in comparison to the common methods of ionization chamber and radiochromic film dosimeter.

2. Methodology

2.1. Experimental set up

The OSL dosimeters were irradiated at high energy photon of 6 and 10 MeV and electrons of 9 and 12 MeV by using Siemen PRIMUS linear accelerator in Nuclear Medicine, Radiotherapy and Oncology Department, Hospital University Sains Malaysia (HUSM) as shown in Figure 1. The solid water phantoms were used to simulate a human soft tissues. A number of three OSL dosimeters were placed at the central axis of the beam at $3 \times 3$ cm field size to simulate the small beams. The small beam in electrons were achieved by using an applicator of $3 \times 3$ cm. A bolus was always placed on top of the OSL dosimeters at depths to minimize the air gaps between the OSL dosimeters and solid water phanom slabs. The exposures were made at 100 cm source to surface distance (SSD) and 100 cGy dose indicated by the monitor unit (MU). The depth doses were measured from the surface until approximately 15 cm and 5 cm depths for high energy photons and electrons respectively while maintaining the SSD.

![Figure 1](image_url)

**Figure 1.** The experimental set up for the irradiation of OSL dosimeters at (a) high energy photons and (b) electrons.

2.2. Data Analysis

The signals of the OSL dosimeters were analysed by using OSL reader model MicroStar InLight at the Malaysian Nuclear Agency (Nuclear Malaysia) [13]. The OSL signals were obtained by calculating the ratio between the photomultiplier tube (PMT) count with the calibration factor given by the equation:

$$\text{Raw Dose (mGy)} = \frac{\text{PMT Count}}{\text{Calibration Factor} \times \text{Sensitivity}}$$

(1)
The dose reading in the OSL dosimeter is obtained by calculating the difference between the initial signal before irradiation with the signal after the irradiation given by the equation

\[
Dose_{OSL} = (\text{Raw Dose} - \text{Initial Dose}) - \text{Control Dose}
\]

(2)

with \text{Control Dose} is the reading in the unexposed OSL dosimeter of the same group.

The percentage depth dose in all dosimeters were calculated by using the equation:

\[
PDD = \frac{Dose \text{ at any depth},d}{Dose \text{ at maximum depth},p_{max}} \times 100\%
\]

(3)

The \text{PDD} at small beams in high energy photons and electrons were also measured by using ionization chamber and Gafchromic EBT3 radiochromic film dosimeters. The \text{PDD} curves by the OSL dosimeters were plotted and compared to the \text{PDD} in ionization chamber and EBT3 film at all experimented energies of photons and electrons.

3. Results and discussion

The plotted \text{PDD} curves of OSL dosimeters at small beam of high energy photons in comparison to the ionization chamber and EBT3 film dosimeters are shown in Figure 2. The \text{PDD} curves of OSL dosimeters at 6 MeV photons were in excellent agreement to those in ionization chamber and EBT3 film as shown in Figure 2(a) with maximum percentage of discrepancies of 4.22 and 1.31% in comparison to the ionization chamber and EBT3 film respectively. The results were in good agreement with the previous works that measured the \text{PDD} of OSL in high energy photons of open field of 10 × 10 cm [10,11]. The \text{PDD} in 10 MeV photons however showed higher percentage of difference between all dosimeters. The \text{PDD} in OSL dosimeters showed maximum percentage of discrepancies of 27.6 and 57.4% in comparison to ionisation chamber and EBT3 film respectively. The results were also consistent with the previous works that indicated higher percentage of discrepancies of OSL readings to those in ionisation chamber and film dosimeters at high energy photons of open field of 10 × 10 cm 10,11].

Higher percentage of differences were observed in higher energy photons due to higher production of ion pairs within the medium that would have different detection among the dosimeters. The percentage difference were more significant between OSL and TLD at higher photon energies due to higher probability of signal fading in the TLD compared to that in OSL [14].

![Figure 2](image-url) The percentage depth dose (PDD) curves of OSL dosimeters in comparison to ionisation chamber and EBT3 film in (a) 6 MeV and (b) 10 MeV photons.
The PDD curves of OSL in electrons in comparison to ionisation chamber and EBT3 film dosimeters are illustrated in Figure 3. The PDD in OSL showed maximum percentage of discrepancies of 10.5 and 13% when measured at 6 MeV electrons in comparison to ionisation chamber and EBT3 film respectively as shown in Figure 3(a). This is due to the high dispersion of electrons at lower energies that would affect the shape of the PDD curves [12]. The PDD in OSL at 12 MeV electrons on the other hand showed lower percentage of discrepancies of below 5% in comparison to ionisation chamber and EBT3 films as shown in Figure 3(b). This is due to the less dispersion of electrons at higher electron energies [12]. The surface dose in OSL showed an excellent agreement within 3% variation in comparison to ionisation chamber and EBT3 films at all experimented electron energies.

![Figure 3](image)

**Figure 3** The percentage depth dose (PDD) curves of OSL dosimeters in comparison to ionisation chamber and EBT3 film in (a) 9 MeV and (b) 12 MeV electrons

The electron beam parameters of electrons in OSL dosimeters, ionization chamber and EBT3 films is shown in Table 1. The electron parameters of OSL dosimeters showed closer values to those in ionization chamber and film dosimeters when measured in higher electron energies. The results very much consistent to the PDD curves of the OSL dosimeters on which the PDD curves in higher electron energies showed better agreement and lower percentage of variations. The electron parameters are often used in radiotherapy treatment planning involving electrons on which the therapeutic range ($R_{80}$ and $R_{90}$) is used to determine the maximum dose to the tumor volumes.

**Table 1.** The electron beam parameters in OSL dosimeters in comparison to ionisation chamber and EBT2 film dosimeters in electrons of 9 and 12 MeV.

| Electron parameters | Depth (cm) | OSL Dosimeters | Ionisation chamber | EBT3 films |
|---------------------|------------|-----------------|--------------------|------------|
|                     |            | 9 MeV | 12 MeV |
| $R_{80}$            |            | 2.59 | 3.02 |
|                     |            | 2.94 | 3.51 |
| $R_{50}$            |            | 3.63 | 4.58 |
| $R_{80}$            |            | 2.35 | 2.93 |
| $R_{80}$            |            | 2.72 | 3.43 |
| $R_{50}$            |            | 3.42 | 4.44 |
| $R_{80}$            |            | 2.21 | 2.82 |
| $R_{80}$            |            | 2.60 | 3.38 |
| $R_{50}$            |            | 3.27 | 4.59 |
A paired sample t-test was conducted between OSL dosimeters and ionization chamber and EBT3 films in all experimented energies of photons and electrons as shown in Table 2 and 3. The results of the paired sample t-test were consistent with the PDD curves as illustrated in Figure 2 and 3. In photons, the depth doses in OSL had no significant differences in comparison to ionisation chamber and EBT3 films when measured at lower photon energies indicated by the p-values (Sig. 2-tailed). The depth doses at higher energy photons however showed significant differences in comparison to ionisation chamber and EBT3 films. The depth dose in electrons however showed no significant differences between OSL dosimeters with ionisation chamber and EBT3 films when measured at higher electron energies. The depth dose at lower electron energies however showed significant differences between OSL dosimeters with ionisation chamber and EBT3 films.

| Energy  | Paired Differences Mean | Std. Deviation Mean | Std. Error Mean | 95% Confidence Interval of Differences | t      | df  | Sig. (2-tailed) |
|---------|------------------------|---------------------|-----------------|--------------------------------------|--------|-----|-----------------|
| 6 MV    | 0.9187                 | 4.12767             | 1.45935         | -2.53207 4.36957                     | 0.630  | 7   | 0.549           |
| 10 MV   | -2.38571               | 4.02189             | 1.52013         | -6.10535 1.33392                     | -1.569 | 6   | 0.168           |
| 9 MeV   | 2.68556                | 3.74496             | 1.24832         | 11.9308 5.56419                      | 2.151  | 8   | 0.065           |
| 12 MeV  | 5.3811                 | 6.24147             | 2.02049         | 10.1783 5.8349                       | 2.586  | 8   | 0.532           |

| Energy  | Paired Differences Mean | Std. Deviation Mean | Std. Error Mean | 95% Confidence Interval of Differences | t      | df  | Sig. (2-tailed) |
|---------|------------------------|---------------------|-----------------|--------------------------------------|--------|-----|-----------------|
| 6 MV    | 0.67238                | 3.07102             | 1.08577         | -1.89507 3.23982                     | 0.619  | 7   | 0.555           |
| 10 MV   | -2.96000               | 7.59024             | 2.86884         | -9.97980 4.05980                     | -1.032 | 6   | 0.342           |
| 9 MeV   | 1.32000                | 1.59030             | 0.50290         | 0.18237 2.45763                      | 2.625  | 9   | 0.028           |
| 12 MeV  | 1.17500                | 1.31250             | 0.41505         | 0.23610 2.11390                      | 2.831  | 9   | 0.520           |

4. Conclusion
The OSL dosimeters showed good depth dose measurements in small beams of high energy photons and electrons. The depth dose of OSL dosimeters showed closer depth dose values to ionisation chamber and EBT3 film dosimeters when measured in lower photon energies and higher electron energies. The electron beam parameters in OSL dosimeters also showed good agreement to those in ionisation chamber and EBT3 films. The overall results indicated the suitability of OSL dosimeters to be used and measurement method for small beams in radiotherapy in the applications of the stereotactic radiotherapy and radiosurgery.

5. References
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