Percentage depth dose measurement in high energy photons and electrons by using the Al₂O₃ optically stimulated luminescent (OSL) dosimeter

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Abstract. The study focused on the measurement of percentage depth dose (PDD) in high energy photons and electrons by using the optically stimulated luminescent (OSL) dosimeters. The beam output calibration was performed on 6 MV photons and 6 MeV electrons and compared to that in the ionization chamber. The PDD was measured in 6 MV photons and 6 MeV electrons and the PDD curves were plotted by using the OSL dosimeters. The PDD curves were compared to that in other common dosimeters including ionization chamber, Gafchromic® EBT2 film dosimeter and the treatment planning software (TPS). The results showed that the beam output calibration measured by using the OSL dosimeters was in good agreement to the ionization chamber within 1.6 and 5.9% percentage of discrepancy for both 6 MV photons and 6 MeV electrons respectively. The measured PDD by using the OSL dosimeters were also in good agreement to the ionization chamber, EBT2 film and TPS software within percentage 13.4 and 10.4% of discrepancies for 6 MV photons and 6 MeV electrons respectively. The overall results indicated the suitability of OSL dosimeters to be used for direct dosimetry measurements in high energy photons and electrons.

1. Introduction
The use of in-vivo dosimeters for dosimetry studies in clinical radiotherapy would help to provide comparison of delivered dose in the patients between the planned and the actual delivered dose. The treatment planning software (TPS) provided a simulation of dose to the target volume taking into account the density and morphology of the tissue volume surrounding it provided by the inputs from the computed tomography (CT) images. The delivered dose to the patients however cannot be measured on the target volume as in-vivo detection is not possible in patients. Therefore several indirect dosimeters such as radiochromic film dosimeter and thermoluminescent dosimeter (TLD) are introduced for in-vivo dose measurements. This is achieved by using the solid water phantoms and anthropomorphic phantoms to simulate the patient. These dosimeters are placed in the region of interest inside the phantom volume to measure the dose delivered from the treatment units.

For the recent years, the use of optically stimulated luminescent (OSL) dosimeter for dosimetry had been increased in the application of dose assessment resulted from the ionizing radiation absorbed
by the human body. In radiotherapy, OSL had been used as an alternative dosimetry technique when rigorous measurement protocols are established especially in radiotherapy and brachytherapy [1-7].

Previous studies suggested the good reproducibility and linear dose response of the optically stimulated luminescent (OSL) dosimeters for standard clinical dose measurements and are suitable for the remoted dosimetry works involving high energy photons and [8][9]. It can be also used in variety of clinical applications such as surface dosimetry, entrance and exit dose measurements, dose mapping and brachytherapy [10-12]. OSL dosimeter utilizes aluminium oxide crystal to include a latticework of dosimetric traps. The typical technical specification and the useful dose range for OSL nanoDots are between 5 and 1500 cGy for general applications. As for medical dosimetry applications, the linear dose response is up to 300 cGy. It also also mentioned that the OSL nanoDots having a very wide operating energy range which is 5 keV to 20 MeV makes it an ideal dosimetry device to use in many dosimetric works application in medical physics including diagnostic imaging X-rays, nuclear medicine imaging dosimetry and radiotherapy dosimetry. It has high sensitivity toward radiation on which it can detect as low as 10 μSv of ionizing radiations.

Percentage depth dose (PDD) is one of the essential parameters to evaluate the attenuation property of a medium and the detection characteristic of a dosimeter [13]. The PDD measurement is commonly measured by using ionization chamber in a water phantom as suggested by many available international dosimetric protocols. Besides the measurement by using the physical dosimeters, the PDD can also being measured by the mean of computer simulations such as the Monte Carlo and treatment planning software (TPS) simulations. This study measured the PDD in 6 MV photons and 6 MeV electrons by using the nanoDot OSL dosimeters based on the proposed method by the international atomic energy agency [14]. The measured PDD using the nanoDot OSL dosimeters were compared to those in the ionization chamber, gafchromic EBT2 film dosimeter and the TPS.

2. Methodology

2.1. Dose Linearity of the OSL Dosimeters

The linearity of the OSL dosimeter to the dose from the photons and electron was determined to measure the behavior of the OSL signals at increased dose of photons and electrons. The OSL dosimeters were irradiated in high energy photon and electron by using Primus linear accelerator at 6 MV photons and 6 MeV electrons. The OSL dosimeters was placed at the central axis of the beam on the solid water phantom by using the source to surface distance (SSD) of 100 cm with the depth of measurement at the depth of maximum dose, d_{max} (approximately 1.5 cm) based on the calibration condition of the available dosimetric protocols (IAEA TRS 398, 2000). Bolus material with approximate thickness of 1.5 cm was placed on the solid water phantom and the SSD was set at 100 cm to the surface of the bolus to ensure that the OSL dosimeters were at the d_{max} as shown in Figure 1. The field size of 10 × 10 cm was used for photons while the applicator of 10 ×10 cm size was used for electrons to provide the field size of the calibration condition. These OSL dosimeters were irradiated at increased dose between 50 and 1000 cGy based on the monitor unit (MU) selection on the control panel (1 cGy = 1 MU).
2.2. Measurement of Percentage Depth Dose in High Energy Photons and Electrons

The PDD in solid water phantoms were measured in 6 MV photons and 6 MV electrons by using the OSL dosimeters. The OSL dosimeters were first placed the surface of the solid water phantoms to measure the surface dose. The dose at depth was measured by placing the bolus material on the depth above the OSL dosimeters to eliminate the air gaps between the solid water phantoms when the OSL dosimeters were present. The SSD was maintained at 100 cm every time the depth was increased. The signals from the exposed OSL dosimeters were sent for readout by using the OSL reader model MicroStar InLight reader (Landauer Inc.). The PDD in OSL dosimeters were calculated by using the equation of

\[ PDD_{\text{OSL}} = \frac{R}{R_X} \times 100 \]  

with \( R \) is the OSL reading at any depth and \( R_X \) is OSL reading of maximum dose (\( d_{\text{max}} \)). The PDD curves were plotted for photons and electrons and compared to that in ionization chamber, EBT2 film dosimeter and the TPS simulations. The percentage difference of the PDD at each depth of measurement was calculated by using the equation:

\[ \text{Percentage difference} = \frac{\text{dose with bolus} - \text{dose without bolus}}{\text{dose without bolus}} \times 100\% \]  

2.3. Measurement of Percentage Depth Dose by Using Ionisation Chamber and Treatment Planning Software

The PDD measurement by using the ionisation chamber was performed based on the department’s quality assurance (QA) method [14]. The PDD was measured by using the solid water phantoms and Markus plane parallel ionisation chamber at 100 cm SSD and 10 x 10 cm\(^2\) field size on the surface. The charges at depths were measured by adding the solid water phantom on the surface while maintaining the SSD. The percentage ionisation depth (PDI) was measured by using the equation:

\[ PDD = \frac{D}{D_{\text{max}}} \times 100\% \]

with \( D \) and \( D_{\text{max}} \) is the dose at depth and maximum dose respectively.

The measurement of PDD by using the treatment planning software (TPS) was carried out by scanning the solid water phantoms by using the computed tomography (CT) scanner. The CT images...
of the phantoms were acquiesced by using the TPS software [15]. The 6 MV photons and 6 MeV electrons were simulated similar to that in the measurement by using ionisation chamber. The dose at depth were calculated based on the CT information provided. The PDD curves in ionisation chamber, and TPS were plotted and compared to that in the OSL nanoDots.

3. Results and Discussion

The linearity of OSL signal measured at the increased dose for 6 MV photons and 6 MeV electrons is illustrated in Figure 2. The results showed that the OSL signals were in good linearity with the increased dose (MU) for both 6 MV photons and 6 MeV electrons shown by the linear regression ($R^2$) values of close to 1. The results were in good agreement with the previous work on the dose linearity of OSL dosimeters in high energy photons and electrons [9]. This indicated that the OSL dosimeters are suitable to be used for the dosimetric studies for photons and electrons doses between 50 and 1000 cGy.

![Figure 2. The OSL signals in cGy at the increased dose (MU) for (a) photons and, (b) electrons.](image)

The measured PDD and the PDD curve of 6 MV photons and 6 MeV electrons by using the OSL dosimeters in comparison to other dosimeters are illustrated in Figure 3. The results showed that the PDD measured by using the OSL dosimeters were in good agreement to that in the other dosimeters of ionisation chamber, EBT2 film dosimeter [16] and the TPS simulation. The comparison of PDD in OSL dosimeter to ionisation chamber as the standard dosimeters by many available international protocols showed an agreement within maximum of 13.4 and 10.4% percentage of discrepancies to other dosimeters in 6 MV photons and 6 MeV electrons respectively [5,17]. The depth of maximum dose $D_{\text{max}}$ measured in OSL dosimeters also showed good agreement to the ionisation chamber, EBT2 film dosimeter and TPS at approximate depth of 1.5 cm for both photons and electrons. The surface dose measured in OSL dosimeter however was lower than all other dosimeters with percentage of discrepancies between 25 and 29% for 6 MV photons and 9.5 and 13.1% for 6 MeV electrons [5,17].
Figure 3. The PDD curves in (a) 6 MV photons and (b) 6 MeV electrons, measured by using OSL dosimeters in comparison to the ionization chamber, EBT2 film and treatment planning system (TPS).

The measurement of dose at the depth of maximum dose, $D_{\text{max}}$, by using the OSL dosimeters in comparison to the output calibration of 6 MV photons and 6 MeV electrons by using the ionisation chamber is presented in Table 1. The results showed that the dose measured by using the OSL dosimeters were in excellent agreement with the ionization chamber with 1.02 and 0.17% percentage of discrepancies for 6 MV photons and 6 MeV electrons respectively. The results indicated the suitability of the OSL dosimeters to be used in the dosimetric studies in high energy photons and electrons.
Table 1. The measured dose at depth of maximum dose, $d_{\text{max}}$, by using OSL dosimeters in comparison to the output calibration by using ionisation chamber at 6 MV photons and 6 MeV electrons.

| Energy  | Dose (cGy)       | Percentage of discrepancy (%) |
|---------|------------------|-------------------------------|
|         | OSL              | Ionisation chamber            |                                |
| 6MV     | 101.63           | 100.6                         | 1.02                           |
| 6MeV    | 94.05            | 93.89                         | 0.17                           |

4. Conclusion
The nanoDot OSL dosimeters showed linear dependency to the increased dose between 50 and 1000 cGy in both 6 MV photons and 6 MeV electrons. The measurement of PDD showed good agreement of PDD curve of the OSL dosimeters to other common dosimetry tools of ionisation chamber, EBT2 film dosimeter and the treatment planning system (TPS) in both photons and electrons. The measured dose at $d_{\text{max}}$ by using the OSL dosimeters showed good agreement to the output calibration of 6 MV photons and 6 MeV electrons by using ionisation chamber. The overall results indicated the suitability of OSL dosimeter for dosimetry works involving clinical photons and electrons.

5. References
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