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ASSESSMENT OF SURFACE DOSE ON THE ART PHANTOM USING THREE-DIMENSIONAL CONFORMAL BREAST RADIOTHERAPY

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ABSTRACT

The assessment of surface dose is essential in radiotherapy to avoid deterministic effect or to reduce the severity of side effects from radiation treatment. In this study, the surface dose for breast cancer radiotherapy was measured using two types of dosimeter; Thermoluminescent Dosimeter (TLD) and Optically Stimulated Luminescent Dosimeter (OSLD). The study was performed on the left breast of female Alderson Radiation Therapy (ART) phantom. The treatment planning was carried out on the ART phantom to determine the homogeneity of dose distribution within the target organ is complied with the tolerance limits of 95% to 107% as recommended by the International Commission on Radiation Units and Measurements (ICRU)'s Report No. 50. From the treatment planning result, the phantom then was irradiated with 267 cGy dose per fraction for two beam fields; medial tangential and lateral tangential fields using a 6 MV photon beam produced from three-dimensional (3D) conformal radiotherapy. Result shows that the OSLD provides 25.7% and 23.5% higher surface dose compared to TLD for medial tangential and lateral tangential fields, respectively. This condition may be due to higher effective point of measurement and angular dependence of the OSLD compared to TLD. As a conclusion, suitable dosimeter should be selected to ensure accurate estimation of surface dose could be made thus reduction of skin reaction to patient could be achieved.

Keywords: Breast radiotherapy, optically stimulated luminescent dosimeter, surface dose, thermoluminescent dosimeter

INTRODUCTION

Breast cancer is one of the most common cancers among women. In Malaysia, female breast cancer contributes to the highest statistic of all female cases with 32.1% compared to cervix and ovary cancer (NCR, 2007). In order to minimize the risk of breast cancer recurrence, usually breast cancer patient is treated using radiation therapy after surgery. However, the radiation therapy can cause adverse skin reactions for breast cancer treatment. Therefore, the assessment of skin dose is important to evaluate the risk of side effects from radiation treatment.

According to the International Commission on Radiological Protection (ICRP)'s Publication 60 and International Commission of Radiation Units and Measurements (ICRU)'s Report No. 39, the skin dose should be assessed at a depth of 70 µm which corresponds to the boundary between the dermis and epidermis layers of the skin (ICRP, 1991 and ICRU, 1985). Although we are able to predict dose to a patient using the radiation treatment planning system (RTPS), however a number of studies have demonstrated that surface and near-surface doses estimated by RTPSs are inaccurate.

One of the reasons is because exist a steep dose gradient in the percentage depth dose (PDD) curve at this depth.

The ultimate check of the actual dose delivered to a patient in radiotherapy can only be achieved by using *in-vivo* dosimetry (ICRU, 1976). The *in-vivo* dosimetry is applied to assess the dose delivered to critical organs such as rectum, vagina and bladder; or in difficult geometries organs where the dose is hard to predict from the treatment plan such as head-and-neck and breast (Costa et al., 2010). Many techniques have been used for *in-vivo* dosimetry, such as semiconductor diodes, thermoluminescent dosimeter (TLD), metal oxide semiconductor field effect transistor (MOSFET) and radiochromic film (Kry et al., 2012, Nakano et al, 2012; Quach et al, 2000).

In this study, the *in-vivo* dosimetry using TLD and Optically Stimulated Luminescent Dosimeter (OSLD) was carried out to measure the breast surface dose for parallel opposed plane using three-dimensional (3D) conformal radiotherapy treatment. The determination of breast surface dose is an importance issue in radiotherapy. This is because the target volume is located closed to the skin where the dose gradient is very steep at this region. Therefore, the skin dose must be accurately estimated to avoid unnecessary skin reactions such as erythema, desquamation and necrosis to the patients.

MATERIALS AND METHODS

Thermoluminescent Dosimeter (TLD) and its Calibration Procedure

The TLD used in this study was TLD-100 powder consists of Lithium Fluoride doped with Magnesium and Titanium (LiF:Mg,Ti) manufactured by Thermoelectron Inc., USA. The TLD-100 powders were annealed at the maximum temperature of 400^{o}C for 1 hour and followed then at 100^{o}C for 2 hour before the irradiation. After annealing, the TLD-100 powders were packaged in the black plastic capsule for calibration (Fig. 1). The capsule is made of opaque polyethylene capsules (IAEA type) of 3 mm diameter, 15 mm length and 1 mm thick walls. Each capsule contains about 50 mg of TLD-100 powder.

The TLD calibration curve for 6 MV photon beams was established using Varian Trilogy Linear Accelerator, type IX Series (Varian Medical System Inc., Palo Alto, California). The calibration procedure is based on the IAEA's TRS No. 398 code of practice (IAEA, 2000). A calibrated 0.6 cm^3 Farmer ionization chamber, type NE 2571 (PTW-Freiburg, Freiburg, Germany) connected to a PTW Unidos electrometer, type 10005 and having a calibration in term of absorbed dose to water for Co-60 traceable to the IAEA Dosimetry Laboratory were used for determining absorbed dose to water. The dosimeters were irradiated at 10 cm depth in water at the beam central axis with 10 cm x 10 cm field size and source-surface distance (SSD) of 100 cm. Five dosimeters were irradiated for absorbed dose of 150 cGy, 180 cGy, 200 cGy, 220 cGy and 250 cGy. One dosimeter was kept as a control for background measurement. Result for TLD was presented as a calibration curve of TL signal (µC) against absorbed dose to water (in cGy). Linear equations and determination coefficients (R^2) for the dosimeter were determined.

After calibration, the dosimeters were re-annealed and then sealed in the transparent plastic for use in the surface dose estimation. Each sample contains about 100 mg of TLD-100 powder (similar amount as in TLD capsule) with effective point of dose measurement at 0.72 mm.

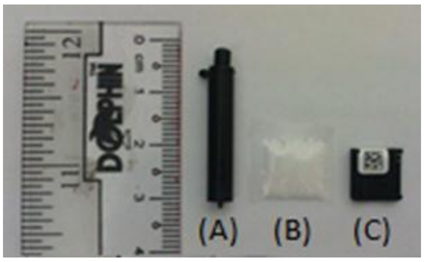

Figure 1: (A) TLD-100 powder encapsulated in the black plastic, (B) TLD-100 powder sealed in the transparent plastic, (C) A nanoDot OSLD

Optically Stimulated Luminescent Dosimeter (OSLD) and its Calibration Procedure

The OSLDs that were used are MicroStar dosimetry system, type nanoDot (Landauer Inc., Gleenwood, Illinois). Comparing with other types of OSLD such as Inlight and DOT, the nanoDOT provides the most feasible dosimeter for single point measurements of skin dose assessment in radiotherapy application due to its small size. The detector material used is Aluminum oxide doped with Carbon (Al_2O_3:C) with 12 mm thickness and 5 mm diameter encased in 10 mm x 10 mm x 18 mm light tight plastic holder (Fig. 1). Before being irradiated, each nanoDot was read using the Inlight reader and the background signal for each OSLD was recorded.

The OSLD was calibrated for 6 MV photon beam produced by a Varian Clinac medical linear accelerator (linac), type 2100C (Varian Medical Systems Inc., Palo Alto, California). The measurement was carried out using solid Gammex water phantom, type 457 (Gammex Inc., Middleton, USA) and 0.5 cm bolus. The phantom consists of various thicknesses from 0.2 cm to 5 cm with dimensions of 30 cm x 30 cm and having density of 1.045 g/cm^3. The detector position was fixed at central axis on 20 cm thickness of solid water phantom. Bolus materials with 0.5 cm thickness and 1.0 cm solid water phantom were placed above the detector. The measurement were carried out at depth of maximum dose of 1.5 cm, SSD of 100 cm and a field size of 10 cm x 10 cm. Five dosimeters were irradiated for absorbed dose of 150 cGy, 180 cGy, 200 cGy, 220 cGy and 250 cGy. One dosimeter was kept as a control for background measurement. Result for OSLD was presented as a calibration curve of OSL signal (in µC) against absorbed dose to water (in cGy), respectively. Linear equations and determination coefficients (R^2) for the dosimeter were determined.

Angular Dependence Measurement Procedure

Study on the angular dependence was carried out using TLD-100 powder and nanoDot OSLD. The detector was placed at the central axis of the beam on 20 cm solid water phantom. The beam field size was adjusted to 10 cm x 10 cm on the phantom surface at 100 cm SSD. The detector was irradiated with 100 MUs and 300 MUs/min at 0^o, 25^o, 50^o, 75^o, 285^o, 310^o and 335^o of beam incidence (Fig. 2). Result of angular dependence for each detector was compared as a relative surface dose against gantry rotation.

Alderson Radiation Therapy phantom and its Treatment Planning

The female Alderson Radiation Therapy (ART) phantom represents a 163 cm tall and 54 kg weight (RadPro International GmbH, Wermelskirchen, Germany) was used in this study. It does not have arms or legs, and the portion utilized in this work corresponds to the left breast. The phantom was constructed with a natural human skeleton cast inside soft tissue simulating material. Two tissue-simulating materials are the soft tissue material with density of 0.997 g/cm^3, designed to have the same absorption as human tissue at the normal radiotherapy exposure levels and the skeleton with 1.61 g/cm^3 density (Abella et al., 2011).

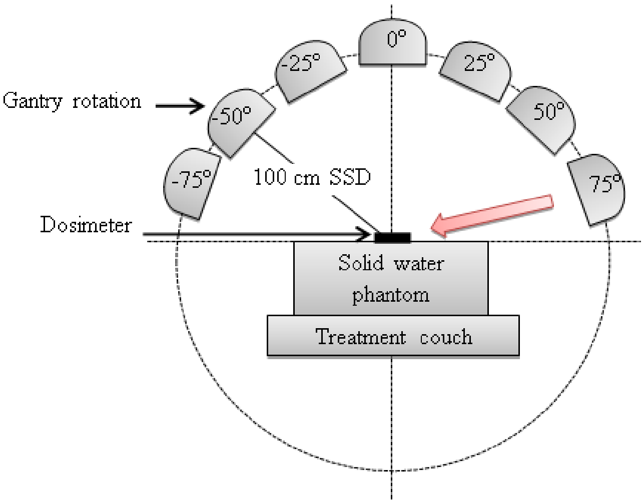

Figure 2: Schematic diagram of angular dependence effects on TLD and OLSD. The gantry was rotated for 25^o, 50^o, 75^o, -25^o,-50^o and -75^o. Dosimeters are placed onto the 20 cm of solid water phantom surface

A parallel opposed plan was applied to the left breast of the ART phantom using Eclipse-radiation planning system (Varian Medical System Inc., Palo Alto, California), version 8.9. The dose distribution was adjusted accordingly to ensure the dose was homogenously distributed within the range of 95% to 107% in target area as recommended by ICRU Report No. 50 (ICRU, 1993). For breast treatment, half beam block was applied to minimize exposure to the critical organ such as lung and heart. A physical wedge of 15 degree was added to both fields.

Procedure of Entrance Surface Dose Determination using an ART Phantom

The ART phantom was positioned on the treatment couch at the same set-up during the CT simulation. Two samples of TLD-100 powder were placed on the breast wall, 3 cm above the phantom chest wall. One sample was placed at the medial and another at the lateral side. The phantom was irradiated with 267 doses per fraction for two beam fields at 126^o and 306^o of gantry rotation with additional of 15 degree physical wedge (Fig. 3). The irradiation was set with dose rate of 300 MUs/min; 197 monitor units (MUs) for left medial tangential field and 195 for left lateral tangential field. The measurements were repeated twice using three different sets of TLD-100 powder and nanoDot OSLDs.

Measurement and Data Analysis

TLD-100 powders

The irradiated TLD-100 powders were analysed using Harshaw TLD reader system, type 3500 manufactured by Thermoelectron Corporation, USA. To ensure good reproducibility of the TLD system, periodic quality control checks including checks of the PMT noise and reference light were carried out. These checks were performed every day before starting the TLD measurement and were repeated on every 10 readings. On average, ten TL signals of 10 mg TLD-100 powder were obtained for each sample. A special TLD dispenser was used to ensure the correct mass of TLD-100 powder was transferred onto the planchet. The TLD-100 powders were heated until the maximum temperature of 300^{o}C with a heating rate of 10^{o}C/s. The net TL signal was calculated from average TL signal from three capsules of irradiated TLDs minus background radiation. The standard uncertainty was calculated based on the TL signals standard deviation.

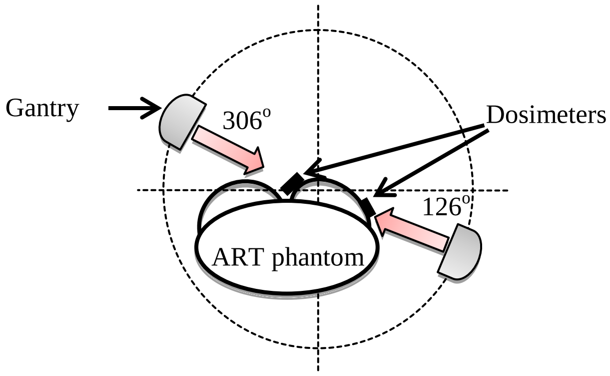

Figure 3: Schematic diagram of surface dose measurements on the ART phantom. Dosimeters are placed onto the breast surface, 3 cm from the chest side wall

NanoDots OSLD

The irradiated nanoDots were evaluated using MicroStar OSL reader system (Landauer Inc., Gleenwood, Illinois). Before being used, the reader was warmed up for at least 30 minutes to allow system stability. Then, the consistency checks of dark current, energy calibration and light intensity from light emission diodes (LED) were ensured to be within acceptable limit of less than 30 counts, ± 30% and ± 30%, respectively. Otherwise, the system should be calibrated using a set of calibration dosimeters provided by manufacturer.

RESULTS AND DISCUSSIONS

Establishment of Calibration Curve

The TLD and OSLD calibration curves for 6 MV photon beam within the range of 150 cGy to 250 cGy was established as shown in Fig. 4. The graphs show that the TL and OSL signal are linearly proportional to absorbed dose to water with gradient of 0.121μC/cGy and 0.639 μC/cGy, respectively. Both graphs also show strong correlation between TL signal and OSL signal with absorbed dose to water with determination coefficient of 0.990 and 0.996, respectively. The linear equations obtained from the graph will be used in determining the surface dose.

Comparison of Angular Dependence between OSLD and TLD

Figure 5 shows the variation of surface dose for different angle of incident beam. Surface doses for 6 MV x-ray using OSLD and TLD were compared. The measured dose was normalized to the surface dose of perpendicular beam incidence. The lines are plotted with the least order polynomial and serve as a guide for the eye. It shows that the incidence of beam entry angle on the phantom surface has a significant effect on surface dose; the more oblique the beam angle the higher the surface dose. This is due to increase of surface dose deposition by the electrons contamination when the photons striking the beam modifier and also electrons produced from backscattered radiation when photons interact in the phantom. For both dosimeters, the maximum angular response is given by 75^o gantry rotation. Comparing with TLD, the OSLD were having small angular dependence 70% of dose response at 75^o beam angle. Therefore, application of angular correction factor is recommended for these detectors when involving the oblique radiation beam.

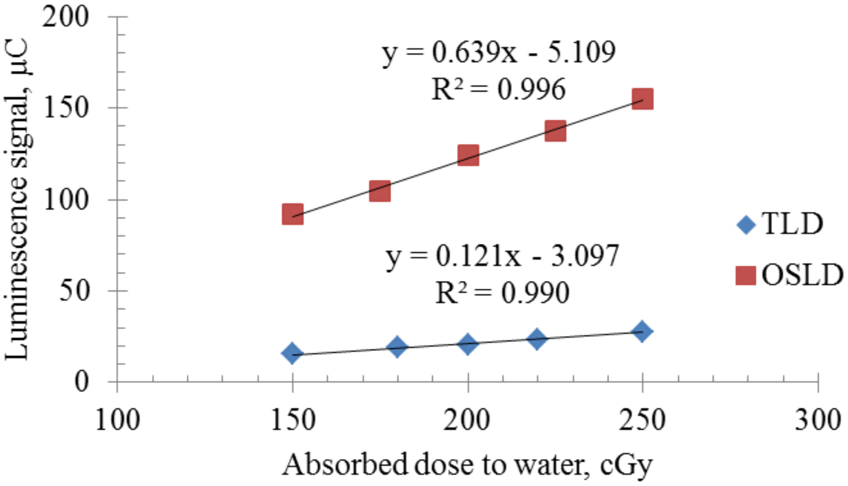

Figure 4: TLD and OSLD calibration curves for 6 MV photon beam. Error bars represent the 1 standard deviation of the mean of five luminescence signals

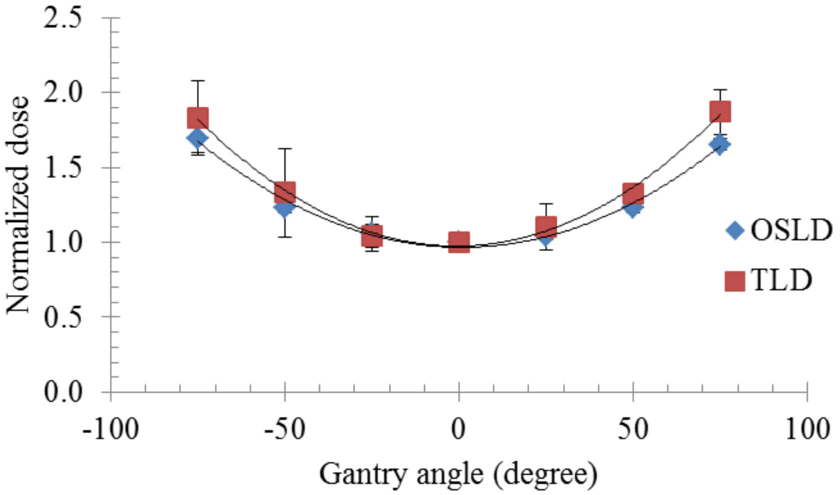

Figure 5: Response of OSLD, TLD with the variation of beam direction. Error bars represent the 1 standard deviation of the mean of three readings

Determination of Breast Surface Dose

The comparison of surface dose for parallel opposed breast treatment plan using TLD and OSLD were made. In order to assess the reproducibility of the measurements, the surface dose for these detectors was measured three times. In the medial tangential field, the surface dose for TLD and OSLD is 110.35 ± 0.70 cGy and 147.68 ± 3.05 cGy. While for lateral tangential, the surface dose for TLD and OSLD is 113.88 ± 0.62 cGy and 148.13 ± 0.18 cGy. For both fields, the OSLD provides higher surface dose than TLD. This is expected because the measurement was done at the build-up region where the change of a few mm of depth may result to significant change in dose. With the effective point of dose measurement at 0.22 mm higher than TLD, OSLD gives the surface dose of 25.28% and 23.12% higher than TLD for medial tangential and lateral tangential fields, respectively.

We also noted that the surface dose at lateral tangential of 306 ° gantry rotation is higher than medial tangential of 126 ° gantry rotation for both TLD and OSLD. This might be due to effect of angular dependence and beam exit dose. In the parallel opposed plan, the beam exit dose may contribute significantly to the surface dose, particularly for small separation body sections such as breast. The exit dose would be similar (~85%) to the percentage depth dose value at this depth. The slight decrease is due to lack of backscatter (Metcalfe et al., 1997). Thus, the surface dose that was measured was actually the combination of entrance and exit dose.

CONCLUSIONS

The measurement of surface dose using thermoluminescent dosimeter and optically stimulated luminescence dosimeter has been investigated on the ART phantom. A parallel-opposed 3D conformal radiotherapy breast treatment was planned and delivered onto a female ART phantom. We found that the surface dose measurement by the OSLD and TLD were comparable with the difference of 25.28% and 23.12% for medial tangential and lateral tangential fields, respectively. The surface dose for lateral tangential field provide higher dose than medial tangential field due to effect of angle incidence of radiation beam and beam exit dose. In addition, the result of higher surface dose given by OSLD than TLD is influence by the different of effective point of dose measurement. Although, surface dose measured using TLD and OSLD does not give an exact estimate of skin dose due to the finite size of the detector, it is nevertheless a useful method for *in-vivo* estimation of skin dose.

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REFERENCES

Abella, V., Miro, R., Juste, B., and Verdu, G. (2011). Comparison of MCNP5 Dose Calculations inside the RANDO® Phantom Irradiated with a MLC LinAc Photon Beam against Treatment Planning System PLUNC, *Progress in Nuclear Science and Technology*. 2: 232-236.

Costa, A.M., Barbi, G.L., Bertucci, E.C., Ferreira, H., Sansavino, S.Z., Colenci, B., and Caldas, L.V. (2010). *In-vivo* dosimetry with thermoluminescent dosimeters in external photon beam radiotherapy, *Appl. Radiat. Isot. 68*(4): 760-762.

International Atomic Energy Agency (IAEA). (2000). Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water, *Tech. Rep. Series No. 398*. Washington D.C.

International Commission on Radiation Units and Measurements (ICRU). (1976). Determination of absorbed dose in a patient by beams of X or gamma rays in radiotherapy procedures, *Report 24*.

International Commission on Radiation Units and Measurements (ICRU). (1985). Determination of dose equivalents resulting from external radiation source, *Report No. 39.*

International Commission on Radiation Units and Measurements (ICRU). (1993). Prescribing, Recording and Reporting Photon Beam Therapy, *Report No. 50.*

International Commission on Radiological Protection (ICRP). (1991). *ICRP Publication 60.* Oxford, UK: Pergamon.

Kry, S.F., Smith, S.A., Weathers, R., and Stovall, M. (2012). Skin dose during radiotherapy: a summary and general estimation technique, *J. Appl. Clinic. Med. Phys.* 13(3): 20-34.

Metcalfe, P., Hoban, P., and Kron, T. (1997). The physics of radiotherapy x-rays from linear accelerators, *Madison: Medical Physics Publishing*.

Nakano, M., Hill, R.F., Whitaker, M., Kim, J. H., and Kuncic, Z. (2012). A study of surface dosimetry for breast cancer radiotherapy treatments using Gafchromic EBT2 film, *J. Appl. Clinic. Med. Phys. 13*(3): 83-97.

National cancer registry report (NCR). (2007). Ministry of Health, Malaysia. Retrieved from http://www.makna.org.my/PDF/MalaysiaCancerStatistics2007.pdf.

Quach, K.Y., Morales, J., Butson, M.J., Rosenfeld, A.B., and Metcalfe, P.E. (2000). Measurement of radiotherapy x-ray skin dose on a chest wall phantom, *Medic. Phys.* 27: 1676-1680.