Technical Note

Verification of Treatment Planning Algorithms Using Optically Stimulated Luminescent Dosimeters in a Breast Phantom

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Abstract

Aim: The aim of this study is to measure and compare the surface dose of treated breast and contralateral breast with the treatment planning system (TPS) calculated dose using calibrated optically stimulated luminescent dosimeter (OSLD) in an indigenous wax breast phantom. **Materials and Methods:** Three-dimensional conformal plans were generated in eclipse TPS v. 13 to treat the left breast of a wax phantom for a prescribed dose of 200 cGy. The plans were calculated using anisotropic analytical algorithm (AAA) and Acuros algorithm with 1-mm grid size. Calibrated OSLDs were used to measure the surface dose of treated and contralateral breasts. **Results:** Large differences were observed between measured and expected doses when OSLDs were read in "reading mode" compared to the "hardware mode." The consistency in the responses of OSLDs was better (deviation <±5%) in the "hardware mode." Reasonable agreement between TPS dose and measured dose was found in regions inside the treatment field of treated breast using OSLDs for both algorithms. OSLD measured doses and TPS doses, for the points where the angle of incidence was almost normal, were in good agreement compared to all other locations where the angle of incidence varied from 45° to 70°. The maximum deviation between measured doses and calculated doses with AAA and with Acuros were 2.2% and-12.38%, respectively, for planning target volume breast, and 76% and 77.51%, respectively, for the opposite breast. **Conclusion:** An independent calibration factor is required before using the OSLDs for *in vivo* dose measurements. With reference to measured doses using OSLD, the accuracy of skin dose estimation of TPS with AAA was better than with Acuros for both the breasts. In general, a reasonable agreement between TPS doses calculated using AAA and measured doses exists in regions inside treatment field, but unacceptable differences were observed for the points lateral to the opposite breast for both AAA and Acuros.

Keywords: Acuros algorithm, analytical anisotropic algorithm, optically stimulated luminescent dosimeter, phantom

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Introduction

Tangential wedge field technique is the commonly used technique for whole-breast radiotherapy. Before delivering radiation to the patient, careful planning and dose simulation are required. The skin dose calculations given by a treatment planning system (TPS) is not accurate as there are many uncertainties in the measurement in the buildup region of high energy X-rays. Hence, *in vivo* dosimetric verification before patient treatment is very important to ensure accurate dose delivery. Furthermore, measurement of the dose to the contralateral breast during breast radiotherapy is important as these low-level radiation doses may induce secondary cancer.[1] In this study, we measured and compared the skin dose of treated breast and contralateral breast with the TPS calculated dose in an indigenous wax breast phantom during whole-breast radiotherapy. Due to the difference in the water equivalent depth (WED) of different detectors, the surface dose varies with the dosimeter used for the measurement.[2,3] Various researchers have studied and measured the surface dose during breast radiotherapy using different phantoms and detectors.[4-7]

Radiochromic films, thermoluminescent dosimeters (TLDs), and MOSFET detectors have been used for surface dose measurements.[4-7] Dose to the breast and scattered dose to the opposite breast were measured in patients, humanoid phantoms, and solid water phantoms using ionization chamber, diodes, TLDs, MOSFET, and Gafchromic films.[8-10] Parallel plate

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chamber was also used for surface dose measurements and measurement of dose in the buildup regions in phantoms.[11-14]

Materials and Methods

Optically stimulated luminescent dosimeter (OSLD) used in this study is a nanoDot dosimeter (Landauer, Inc., Glenwood, IL, USA) which is a plastic disc of diameter 5 mm and thickness 0.2 mm infused with aluminum oxide doped with carbon (Al_2O_3: C) and is encased in a light-tight plastic holder of dimension 1 cm × 1 cm × 0.2 cm. This is read using the MicroStar reader (Landauer, Inc., Glenwood, IL) after 8–20 min.[15] When exposed to ionizing radiation, the dosimeter stores energy that is released as luminescence (420 nm) when it is stimulated with green light (540 nm). The intensity of the luminescence depends on the dose absorbed by the OSLD and the intensity of the stimulating light.[16]

For the study, we calibrated the nanoDot OSLDs on a linear accelerator (LINAC) with the output verified according to the TRS 398 protocol[17] using a calibrated cylindrical chamber. Thirty-five OSLDs were calibrated independently in a 6 MV X-ray beam in polymethyl methacrylate (PMMA) phantom with slabs of 1-cm thickness for 15 cm × 15 cm field size at 5-cm depth in source-surface distance setup. Before the irradiation of OSLDs, a Farmer-type ionization chamber (model FC-65G) was used for measuring the output of the machine for the same setup. PMMA slabs of up to 10-cm thickness were placed beneath the chamber and nanoDot OSLDs to provide sufficient backscatter.

The measured output was used for calculating the monitor units required to deliver a reference dose of 50 cGy to the selected OSLDs. The chamber was replaced by a fresh batch of 35 OSLDs, and all of them were exposed simultaneously to a reference dose of 50 cGy at 5 cm depth. This depth was chosen for the calibration of OSLDs to avoid the uncertainties that may arise due to the placement of detectors at the surface or buildup region. To keep the OSLDs exactly at a depth of 5 cm; a 2-mm thick PMMA sheet was fabricated with 1 cm × 1 cm square slots (a total of 81 slots with 5 mm gap between them) at the center of the sheet. Three readings (counts) were taken for each dosimeter and the average value of counts given by each OSLD was taken. The "hardware test" mode and "high dose" setting in the reader were selected which use low-intensity LED-beam for all the measurements. The calibration factor (CF) in cGy/counts was obtained as the ratio of the reference dose delivered to the OSLD to the net counts. The net counts were the average of three readings after irradiation minus the average of three readings before irradiation. The net counts given by each OSLD were taken and the CF for each OSLD was calculated. The calibrated OSLDs were irradiated to a dose of 100 cGy in PMMA slab phantom with the same setup and the percentage deviation between measured and delivered doses was calculated. Figure 1 shows the arrangement of OSLDs on the PMMA slab phantom and the setup for calibration respectively.

There are two modes for the read-out of OSLDs in the MicroStar reader-"Reading Mode" and "Hardware mode". To compare the two modes, the calibrated OSLDs were read in both modes, and the deviations of the measured dose from the expected dose were calculated. The OSLDs were exposed to 100 cGy again after 1 week with and without annealing, to check the consistency in dose measurement and to rule out experimental errors. The OSLDs were read at 20 min and after 24 h to check the fading of the signal.

The linearity of the OSLDs was checked by exposing a batch of 4 OSLDs each to doses of 50, 100, 150, 200, and 300 cGy, respectively, and the mean value of the measured dose was noted for each dose value and compared with the delivered dose.

Preparation of wax breast phantom

A breast phantom was prepared with paraffin wax using a female mannequin of medium size as mold. The melted wax of approximately 20 kg was used for the preparation. Thermocol sheets of thickness 15 cm were shaped and kept inside the phantom to simulate human lungs. By pouring wax over thermocol, the total phantom thickness was made 25 cm. It was allowed to cool (18–20 h) for the wax to set properly. A hole with 8-mm diameter was drilled inside the left breast of the phantom approximately 6 cm inside the breast below 5 cm from the nipple level in the craniocaudal direction to insert a micro ion chamber (A-14 Exradin ion chamber with sensitive volume 0.015 cc) inside it with the tip at the center of the breast [Figure 2].

Optically stimulated luminescent dosimeter measurements in the phantom

Calibrated OSLDs were used for measuring the surface dose to the planning target volume (PTV) of breast and contralateral breast in the phantom. Computed tomography (CT) scans of the phantom were taken with OSLDs placed on the surface of both breasts. Ten different OSLDs (other than the one which was selected for CT) were placed on the phantom at the same ten locations (5 on each breast) to measure the dose. Exradin A-14 SL (standard imaging) micro ionization chamber with collecting volume of 0.015 cc was also kept inside the left breast during scan acquisition. The purpose was to verify the accuracy of the anisotropic analytical algorithm (AAA) and Acuros in dose estimation at the center of the PTV breast, where the prescription point is defined. Scans of 1.25 mm

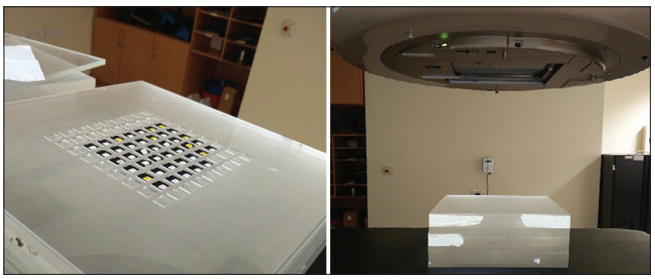

Figure 1: Setup of optically stimulated luminescent dosimeters for calibration

slice thickness were acquired in a GE Optima 580W 16 slice CT simulator. The positions of OSLDs were inferior, superior, medial, lateral, and one at the nipple level. Three lead markers were placed on the phantom to set the origin. The acquired images were exported to the Eclipse (V-13) TPS and plans were generated for Clinac 600C machine with a medial and a lateral tangent beam with 30° physical wedge to treat the left breast of the phantom. The isocenter was placed at the center of the left breast. The OSLDs were contoured in the TPS plan and named as right inferior, right superior, right medial, right lateral (RL), right nipple, left inferior, left superior, left medial (LM), left lateral and left nipple. The dose was normalized to 100% in the midplane of the left breast, where a reference point called weight point was selected to prescribe the dose. This point was placed 2–3 cm anterior to the lung on the central axial slice and at a transverse distance of 8.8 cm from the midline on the left breast of the phantom. The dose prescribed to the weight point was 200 cGy. The analytic anisotropic algorithm (AAA, V-13), and Acuros algorithm (V-13.7.14) with grid size 1.0 mm and heterogeneity correction was used for dose calculation. The TPS calculated mean dose with AAA and Acuros at the surface of treated breast and contralateral breast were noted for the ten OSLDs from the dose volume histograms (DVHs) and compared with the measured dose. Furthermore, the mean chamber dose at the center of left breast was noted from the DVH for comparing with ion chamber measured dose.

The phantom was set in the treatment machine with the isocenter at the center of the left breast. Figure 3 shows the setup of the phantom for measurement in the Clinac machine.

The treatment plans calculated with AAA and Acuros were executed in the machine for three fractions on different days of the week with the same setup, and the average of these measurements was taken and compared with the TPS calculated dose. The OSLDs placed on the PTV breast were irradiated for 2 Gy so that their dose-response is in the linear region. To ensure adequate signal to OSLDs placed on the opposite breast, PTV breast was exposed to 10 Gy. Before each fraction, the OSLDs were optically annealed, and precounts were noted and then irradiated for the next fraction. All the OSLDs were read three times and the average of the three readings was taken to derive the measured dose. The measured dose using ion chamber also was obtained by executing the plans calculated with AAA and Acuros and compared with the calculated mean dose of the chamber from the DVH.

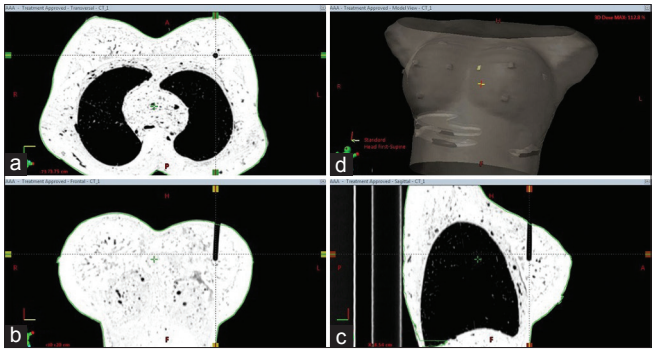

Figure 2: Images of the wax breast phantom taken in computed tomography simulator showing the hole for chamber insert. (a) Transverse view. (b) Coronal view. (c) Sagittal view. (d) Three-dimensional view

Results and Discussion

The mean value of counts obtained by 35 OSLDs was 2722 ± 78 (standard deviation [SD]) counts for the reference dose of 50 cGy. The CF for each OSLD was obtained, and the average value of the CF of 35 OSLDs was 0.0180±0.0004 (SD). The variation in response from detector to detector could be easily managed by establishing and applying individual CF of each OSLD by this method.

Large differences were found between measured and expected dose when OSLDs were read in reading mode compared to the hardware mode. Out of 35 dosimeters, only 9 OSLDS showed <5% deviation, whereas 6 OSLDs showed deviations between 5% and 10% and 20 OSLDs showed deviations >10% from the expected dose. However in the hardware mode, 17 out of 35 OSLDs showed deviations <5%, 15 OSLDs showed deviations between 5% and 10% while only 3 out of 35 OSLDs showed deviations >10%. The consistency in the response of OSLDs was better (deviation < ±5%) in the "hardware mode". Hence, we used hardware mode for the OSLD readout in our phantom study.

The deviations were reduced further when OSLDs were annealed before every use. In the case of annealed OSLDs, 25 out of 35 dosimeters showed deviations of ±5% when exposed to a dose of 100 cGy. Remaining 10 OSLDs showed an over-response of 5%–8.7%. These ten dosimeters were omitted from the study. The response of OSLDs was found to be linear up to the dose range of 300 cGy. Linearity between the delivered dose and measured dose showed excellent correlation ($r = 0.99$) in good agreement with published reports.[18-20]

To check the consistency of calibrated OSLDs, these were again exposed to a dose of 100 cGy after 1 week. Similar results were found for the same OSLDs. The OSLD which gave better response earlier (<5% deviation) gave similar results. The counts obtained after 24 h also showed the same deviation, but with a reduction in the dose by 0.9% (mean) probably due to fading.

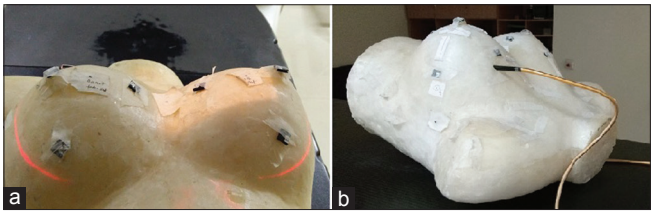

Figure 3: Set up of the breast phantom with optically stimulated luminescent dosimeters and ionization chamber for measurement. (a) Front view. (b) Lateral view (with chamber inserted)

Optically stimulated luminescent dosimeter measurements in the phantom

OSLD measurements were done in the breast phantom to compare TPS dose with the measured dose for the two algorithms. The results given in Table 1 show that the OSLD measured dose and TPS dose for the point LM is the lowest (where the angle of incidence is almost normal) compared to all other locations (where the angle of incidence varies between 45° and 70°). Although the level of accuracy in surface dose estimation by a TPS is within ±25%, it may vary depending on the accuracy of the percentage depth dose data acquired in the buildup region for the beam data modeling of the TPS. In this study, the maximum deviation between the measured dose and the calculated dose was 2.2% for PTV breast and nearly 76% for opposite breast with AAA. Table 1 shows the measured doses, the TPS calculated doses and percentage deviations at various locations using AAA and Acuros algorithms for both breasts. The deviations were larger for Acuros for both breasts compared to AAA. The maximum deviation between measured and calculated dose with Acuros was - 12.38% for PTV breast and 77.51% for opposite breast. Reasonable agreement between TPS dose calculated using AAA and the measured dose was found in regions inside the treatment field.

The maximum deviation between TPS dose and measured dose was found for the point lateral to the opposite breast RL which was the farthest point from the field edge. The deviation was almost the same for both AAA as well as Acuros for this point (76% and 77.5%). Measured dose was high at this point when compared to TPS dose. The dose outside the treatment field varies with the distance from the field edge and the important source of dose contribution at these distances will be the head leakage from the machine which the TPS does not take into account accurately. Kry reported an over-response of dose >30% using OSLDs outside the radiation field due to the contribution of the soft spectrum of X-rays.[21] Howell *et al*. reported that the Eclipse TPS underestimated out-of-field dose by up to 55% at 11.25 cm from the treatment field border.[22] The highest variation of 76%–77.5% on the opposite breast might be due to the combined effect of underestimation shown by TPS and over-response of OSLDs.

The calculated dose from TPS (mean dose of chamber volume) for AAA and Acuros and the dose measured using A14 chamber at the center of the breast is also given in Table 1. A deviation of only 1% and 1.2% was observed for AAA and Acuros, respectively.

In the case of annealed OSLDs, a deviation of ±5% between OSLD measured dose and expected dose could be achieved when calibrated in the "hardware mode" for 80% of the detectors. However, 20% of the detectors showed an over-response of >5%. With the increase in the accumulated dose, the response of OSLDs was found to be erratic and undesirable. With annealing before each measurement, this could be reduced, and a deviation of <5% between predicted and measured dose could be achieved. The curve fitting estimate advised by Landauer (Reading mode) is the usual procedure which in our experience gives a large variation in the dose as compared to the protocol described above. An independent CF for each OSLD and annealing before each measurement reduces the inaccuracy in measurements. The fading of OSLD signal over 24 h was 0.9%. Several papers have reported that OSLD exhibits a fading effect of about 2% between 1 and 24 h, 3% afterward up to 2 weeks and the rate of fading decreases as time passes.[18,20]

Table 1: Comparison of OSLD measurements with AAA and Acuros calculated treatment planning system doses in wax breast phantom for 200 cGy

OSLD position	AAA			Acuros		
	MT (204 MU) LT (231 MU)			MT (218 MU) LT (218 MU)		
	Measured dose (cGy) Mean±SD	TPS dose (cGy)	Deviation (%)	Measured dose (cGy) Mean±(SD)	TPS dose (cGy)	Deviation (%)
RS	10.80±0.48	11.2	−3.73	10.32±0.70	8.2	21.5
RI	13.70±0.26	13.5	1.48	13.35±0.56	9.6	28.9
RN	18.40±0.27	19.2	−4.33	18.10±0.72	12.2	32.6
RL	9.20±0.16	2.2	76.07	9.34±0.07	2.1	77.5
RM	25.98±0.83	27	−3.92	23.14±1.1	25.4	−10.2
Mean	15.62	14.6		14.85	11.5	
LS	145.38±5.5	145.1	0.19	143.80±2.6	161.6	−12.38
LI	143.97±2.4	140.8	2.20	138.80±11.3	147.2	−5.98
LN	124.27±3.8	124.2	0.06	127.09±12.5	134.0	−5.44
LL	130.81±6.0	131.0	−0.14	132.84±2.1	138.0	−5.39
LM	114.58±3.1	116.0	−1.33	113.69±7.9	117.4	−3.26
Mean	131.8	131.4		131.2	140.0	
Chamber measured dose at Centre of PTV breast	201.96	200	1.0	202.54	200	1.2

RI: Right inferior, RS: Right superior, RM: Right medial, RL: Right lateral, RN: Right nipple, LI: Left inferior, LS: Left superior, LM: Left medial, LL: Left lateral, LN: Left nipple, MT: Medial tangent, LT: Lateral tangent, MU: Monitor unit, OSLD: Optically Stimulated Luminescent Dosimeter, AAA: Analytical anisotropic algorithm, PTV: Planning target volume, TPS: Treatment planning system, SD: Standard deviation

Several authors have compared TPS calculated surface dose with measured dose and have reported overestimation as well as underestimation of the surface dose by OSLD.[23-25] One reason for the variations in estimation is that the measurements were done at the build-up region where the change of a few mm of depth may result in a significant change in dose. Second, OSLD which has a WED of 0.4 mm overestimates the surface dose when compared to detectors which have a lower WED. Positional errors in the placement of OSLD during measurement may also contribute to the variation between TPS calculated dose and measured dose.

The scatter dose to the contralateral breast was 3%–36% of the prescribed dose as reported in several studies.[26-28] In our study, with AAA, the dose to skin of the opposite breast was 7.8% versus 7.3% (measured vs. TPS taking average of all the measurements) and the dose to skin of PTV breast was 65.9% versus 65.7% (measured vs. TPS taking average of all the measurements) of the prescribed dose. With Acuros, the values were 7.4% versus 5.74% (measured vs. TPS) and 66% versus 70%. For AAA, reasonable agreement between TPS planned dose and the measured dose was found in regions inside the field and outside the field. The deviations were larger for Acuros for both breasts compared to AAA. Several studies have reported that the accuracy of Acuros is better than AAA in predicting dose within heterogeneous media for 6 MV photons. However in our experience, doses calculated with AAA agreed well with measured values for surface dose. Large discrepancy between measured and calculated doses was shown by Acuros for opposite breast. At the center of the PTV breast, both AAA and Acuros showed deviations <2% with measured dose.

Conclusion

Proper calibration of OSLDs is essential for *in vivo* dose measurements. An independent CF and proper annealing before every use reduces the errors in measurement. A deviation of < ±5% could be achieved in the "hardware mode" for 80% of the detectors. An indigenously prepared wax breast phantom was used for dose measurement with OSLDs that could effectively be used to verify TPS calculated surface doses of PTV breast with measured dose with reasonable accuracy even though differences between the same was observed for the contralateral breast. While planning treatment for breast radiotherapy, choosing AAA or Acuros algorithm for dose calculation does not make any significant difference in the level of accuracy in dose delivery at the center of the breast. With reference to measured doses using OSLD, the accuracy of skin dose estimation of TPS with AAA was better than with Acuros for both the breasts. A reasonable agreement between TPS doses calculated using AAA and measured doses exists in regions inside treatment field, but unacceptable differences were observed for the points lateral to the opposite breast for both AAA and Acuros.

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Conflicts of interest

There are no conflicts of interest.

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