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Andrew Kelly
University of Wollongong, ak989@uow.edu.au

Nicholas Hardcastle
University of Wollongong, nhardc@uow.edu.au

Peter E. Metcalfe
University of Wollongong, metcalfe@uow.edu.au

Dean L. Cutajar
University of Wollongong, deanc@uow.edu.au

Alexandra Quinn
University of Wollongong, aq908@uowmail.edu.au

See next page for additional authors

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Surface dosimetry for breast radiotherapy in the presence of immobilization cast material

Andrew Kelly[1], Nicholas Hardcastle[1,2], Peter Metcalfe[1], Dean Cutajar[1], Alexandra Quinn[1], Kerwyn Foo[3,4], Michael Cardoso[1], Sheree Barlin[5] and Anatoly Rosenfeld[1]

[1] Centre for Medical Radiation Physics, University of Wollongong, Wollongong, NSW, Australia
[2] Department of Human Oncology, University of Wisconsin, Madison, WI, USA
[3] Sydney Medical School, University of Sydney, Sydney, NSW, Australia
[4] Royal Prince Alfred Hospital, Sydney, NSW, Australia
[5] Illawarra Cancer Care Centre, Wollongong Hospital, Wollongong, NSW, Australia

E-mail: anatoly@uow.edu.au

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Abstract

Curative breast radiotherapy typically leaves patients with varying degrees of cosmetic damage. One problem interfering with cosmetically acceptable breast radiotherapy is the external contour for large pendulous breasts which often results in high doses to skin folds. Thermoplastic casts are often employed to secure the breasts to maintain setup reproducibility and limit the presence of skin folds. This paper aims to determine changes in surface dose that can be attributed to the use of thermoplastic immobilization casts. Skin dose for a clinical hybrid conformal/IMRT breast plan was measured using radiochromic film and MOSFET detectors at a range of water equivalent depths representative of the different skin layers. The radiochromic film was used as an integrating dosimeter, while the MOSFETs were used for real-time dosimetry to isolate the contribution of skin dose from individual IMRT segments. Strips of film were placed at various locations on the breast and the MOSFETs were used to measure skin dose at 16 positions spaced along the film strips for comparison of data. The results showed an increase in skin dose in the presence of the immobilization cast of up to 45.7% and 62.3% of the skin dose without the immobilization cast present as measured with Gafchromic EBT film and MOSFETs, respectively. The increase in skin dose due to the immobilization cast varied with the angle of beam incidence and was greatest when the beam was normally incident on the phantom. The increase in surface dose with the immobilization cast was greater under entrance dose conditions compared to exit dose conditions.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Breast radiotherapy presents a number of technical challenges to clinicians when treating large breasted women (Pidcock and Rattray 2002). Curative breast radiotherapy typically leaves patients with varying degrees of cosmetic damage (Fernando *et al* 1996, Holli *et al* 2002). The amount of damage depends on many factors including breast size, shape, genetics, and generally, what type of breast radiotherapy is employed (Fernando *et al* 1996). One problem interfering with cosmetically acceptable breast radiotherapy is the external contour for large pendulous breasts. These often result in high doses to skin folds. One approach to the pendulous breast problem is through use of immobilization cast devices. These are typically in the form of exoskeleton-type shells or rings placed around the breast to prevent mobility with the patient in the supine position (Latimer *et al* 2005). Immobilization devices are used extensively already for head and neck treatments, purely for the purpose of immobilization and setup error reduction. For use with breast radiotherapy there are additional potential advantages. The first of these being a shift in breast tissue antero-medially which could lessen the amount of lung/heart tissue within the field. The second advantage is a reduction in skin folds receiving high dose, and the third, a reduction in breast separation that has previously been shown in prone therapy to improve dose homogeneity.

The primary disadvantage of using an immobilization cast is that it might provide a bolus effect to the entire breast surface. The effect of bolus material on skin dose has been measured in previous studies (Chiu-Tsao and Chan 2010, Hsu *et al* 2008, Lee *et al* 2002, Quach *et al* 2000). Lee *et al* (2002) showed, using thermoluminescent dosimeter (TLD) detectors, that the surface dose for head and neck radiotherapy increased due in part to the bolus effect of immoblization cast material which contributed to increased skin toxicity. Quach *et al* (2000) measured the surface dose on a hemicylinder phantom irradiated with 6 MV photons and found that the highest surface dose was at the apex of the hemicylinder, that is, when the beam was tangential to the surface of the phantom. The addition of 1 cm bolus material increased the surface dose for beam entrance locations by up to 350%; however this decreased at tangential and beam exit locations to approximately 10%. Hsu *et al* (2008) measured the surface dose on both slab and anthropomorphic phantoms for a variety of bolus materials. The authors found that surface dose increased with more tangential beams and that surface dose increased with bolus materials. The increase in surface dose however decreased as the beams became more tangential. Chiu-Tsao and Chan (2010) carried out a comprehensive set of measurements of skin doses with radiochromic film in the presence of various immobilization devices. For 6 MV photons normally incident on a slab phantom, thermoplastic mesh material resulted in a surface dose (at 153 μm water equivalent depth (WED)) increase of 170–280%, relative to the surface dose measured with no thermoplastic material present. The dose increase depended on whether the point of measurement was under a hole or a strut of the mesh.

The current study aims to quantify any increase in surface dose attributed to a particular immobilization cast. The surface dose for a hybrid conformal/IMRT breast treatment plan was measured on an anthropomorphic phantom using radiochromic film and a MOSFET detector specifically designed for skin dosimetry, the MO*Skin*^{TM} (Kwan *et al* 2008).

2. Methods

2.1. Treatment plan measurements

A rigid anthropomorphic phantom was employed for dosimetry in this study. The phantom was constructed of tissue analog material with removable breasts, such that a range of sizes

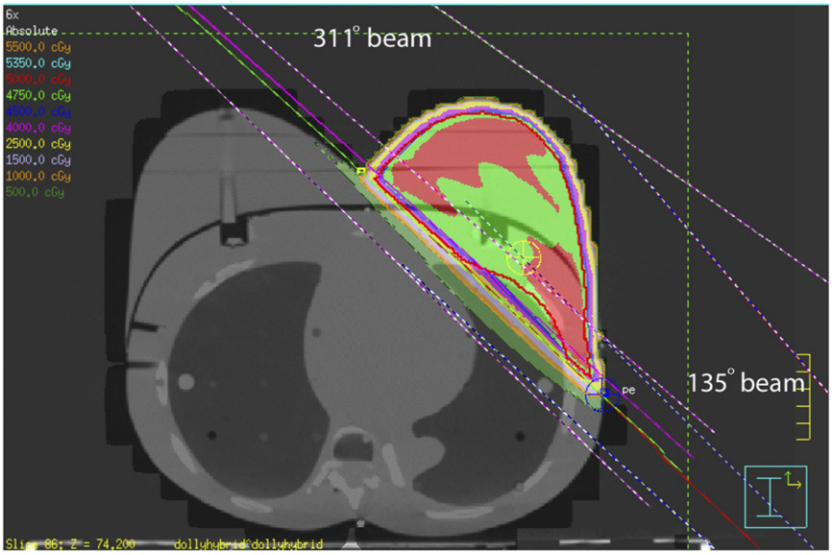

Figure 1. Axial view of the anthropomorphic phantom with opposed tangents.

can be used for dosimetry as required. The breast size used for this study was D-size, since pendulous breasts are roughly this size and above. With the D-sized breasts in place, the phantom was scanned on a Siemens Sensation Open CT for radiotherapy treatment planning. An IMRT plan was created using the P3IMRT tool in the Pinnacle treatment planning system (v8.0, Philips Medical Systems, Fitchburg, WI, USA). The plan consisted of four fields: an open and a modulated field from each of two opposed gantry angles (311° and 135°, IEC Convention (IEC 1996)). The goal of the IMRT optimization was to minimize hot dose spots throughout the breast, and in general deliver as homogeneous a dose distribution throughout the breast volume as possible. The dose distribution in a transverse slice is shown in figure 1.

The phantom was irradiated using a Varian 2100C (Varian Medical Systems, Palo Alto, CA, USA) linear accelerator, with the phantom positioned upon an Alpha-cradle (Smithers Medical Products, Inc., OH, USA) in the supine position. An Orfit immobilization device (Orfit Industries America, NY, USA) was molded to the phantom. The phantom was aligned using room laser alignment to markers placed at the time of simulation.

2.2. Film dosimetry

Gafchromic EBT film was used (International Specialty Products, NJ, USA). The active layer of the film is at a WED of 153 μm (Devic *et al* 2006) and was used to measure dose slightly deeper than 70 μm, the ICRP-recommended average depth of the radiosensitive basal cell layer in the skin (ICRP 1991). This dosimeter was used for its ability to obtain 2D dose maps. It is also interesting to obtain dose measurements slightly deeper than 70 μm as the epidermal layer of the skin can vary in thickness (ICRP 1975). The film was prepared by cutting sheets into 1.5×25 cm^2 strips for placement on the phantom surface at points of interest. A set of calibration films were irradiated at the time of experimentation and all films scanned approximately 24 h later. This was to take into account sensitivity differences between batches of film and eliminate the optical density dependence of readout on time after irradiation (Soares 2006).

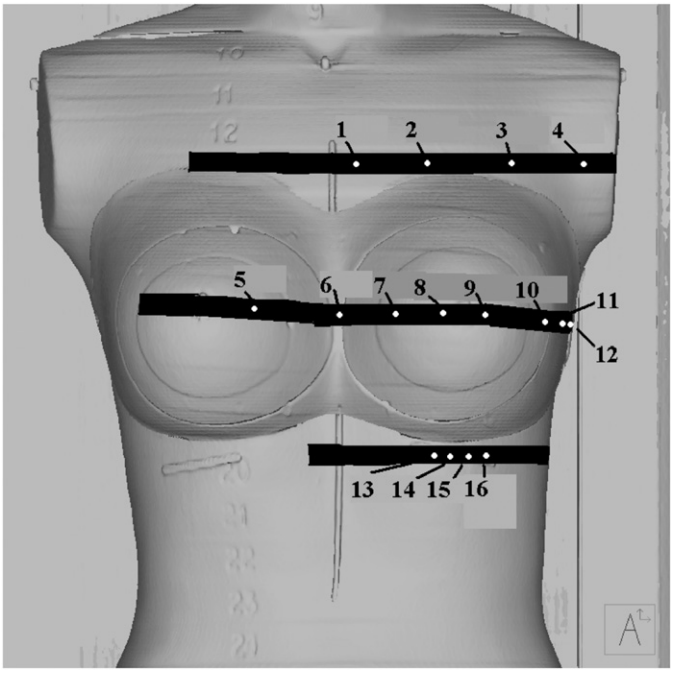

Figure 2. Detector locations. Black strips represent approximate film locations; white spots indicate approximate MOSFET points.

Film was scanned using an Epson Perfection V700 (Epson America Inc., Long Beach, CA, USA) scanner in reflective mode in the center of the field, as this improves scanner uniformity (Kalef-Ezra and Karava 2008). Scans were performed at 16 bit per color channel and 72 dpi. Scanning at greater resolution than 72 dpi provides no great advantage (Martisikova *et al* 2008). Data was taken from the red channel only, as this corresponds closely to the maxima on the absorption curve for Gafchromic films, achieving greatest scan sensitivity. All films were used within the manufacturer specified dose range. Calibration and measurement films were scanned in the same orientation to minimize this source of error.

Film was placed on the phantom surface in the medial to lateral direction as shown in figure 2. The first strip of the film went from the manubrium, across isocenter, toward the axilla. The second strip went from the apex of the contralateral breast, across the sternum, over the apex of the ipsilateral breast, and down to the anterior/posterior simulation tattoo. The third strip went from approximately the xiphoid, along the inframammary fold region and down the chest wall laterally. The film outlines were drawn on the phantom to permit accurate placements of further film as required (for each tangential beam). The points for film dosimetry were chosen as they are reported sites of skin toxicity for breast irradiation and as such are of clinical interest (Donovan *et al* 2007, Fernando *et al* 1996).

2.3. MOSFET dosimetry

MOSFET dosimeters were used to obtain point dose measurements at various positions of interest also measured by the film. The MOSFET detector used for these measurements was

the MO*Skin*. The MO*Skin* has a WED of measurement of 70 μm, the ICRP-defined depth of the radiosensitive basal layer in the skin (ICRP 1991). A feature of the MO*Skin* is that it can be read out in real time, allowing for resolution of each individual field's contribution to the total dose distribution. The MO*Skin* detector system has been used previously for skin and surface dosimetry (Hardcastle *et al* 2008, Kwan *et al* 2008). The MOSFETs were read out in real time using a computerized reader developed in-house (Center for Medical Radiation Physics, University of Wollongong, Australia). Calibration of the MOSFET dosimeters was undertaken at 100 cm source to surface distance, with the dosimeter at d_{max} (1.5 cm) using a 10 $\times$ 10 cm^2 field. The MOSFET detector sensitivity slightly decreases, within 5%, with absorbed dose; therefore greater accuracy in measurements can be obtained by using an average of the calibration factors before and after particular measurements are obtained. The calibration of the MOSFET detectors and all measurements were carried out at the same temperature to remove the effects of temperature variation on measurements. All MOSFET measurements were carried out three times to obtain measurement variance.

Real-time dosimetry for each of the 16 MOSFETs was performed at a frequency of 1 Hz using a CMRP MOSFET reader. This allowed visualization, on a graphical display using in-house-developed software, of the contribution from each open and modulated field to the overall surface dose in real time. The sensitivity of the MOSFET depends on gate bias. The linearity of the response and sensitivity was improved by applying a +15 V gate bias to the MOSFET. The read-out process does not affect the final measured dose, as the gate voltage is only inverted for 0.01% of the duty cycle; the sensitivity of the MOSFET is only affected for 0.01% of the total irradiation time.

MOSFETs were taped onto the phantom at measured intervals along the film dosimetry positions to obtain point doses for comparison with film. The locations of the MOSFET detectors are shown in figure 2. Care was taken to have no air gaps behind the dosimeters and to ensure the tape was not covering the sensitive volume of the MOSFETs. The film and MOSFET measurements were carried out in separate irradiations to prevent the interference of one dosimeter with the other. The treatment involved two opposed fields, with multiple segments within each field. Therefore, film and MOSFET data was taken for both gantry angles, with and without Orfit, so that entrance and exit dose to the dosimeters could be separated.

2.4. Effect of immobilization cast thickness on surface dose increase

The immobilization cast thickness varies with the amount the material is stretched. At regions of high electronic disequilibrium such as at the surface, the change in thickness will have a large effect on the measured dose. The variation of surface dose increase with the cast thickness was measured. A MOSFET was placed on the surface of a slab phantom. Two immobilization casts were created to cover the MOSFET. The first cast had limited stretching and had holes of 2.2 $\times$ 1.8 mm $\pm$ 0.1 mm and was 1.5 $\pm$ 0.2 mm thick (referred to as 'thick Orfit'). The second cast was stretched to be thinner, with larger holes of 6.2 $\times$ 2.3 mm $\pm$ 0.1 mm and was 1.2 $\pm$ 0.1 mm thick (referred to as 'thin Orfit'). For reference, unstretched Orfit material is approximately 2.6 mm thick. The surface dose was measured with the MOSFET both under cast material and under a gap in the material for both casts and without a cast. The variation in measured surface dose with incident beam angle, from 0° to 85°, was also measured.

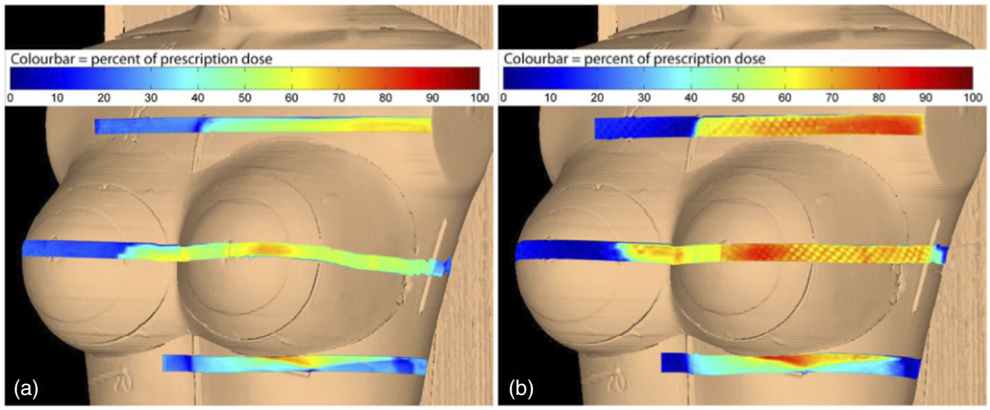

Figure 3. Film measurements (a) without the immobilization cast present, and (b) with the immobilization cast present.

3. Results

3.1. Film and MOSFET measurements

Figure 3 shows the digitized film images converted into normalized dose (normalized to the prescription dose of 2 Gy). The digitized film images have been overlaid onto their respective locations on the phantom. The presence of the Orfit immobilization cast during irradiation can clearly be identified in figure 3 by the presence of significant dose increases observed at the axilla, breast apex, and inframammary fold regions. The cross-hatched pattern is a result of the bolus effect of the cast material. This cross-hatching pattern is more evident where the surface is more normal to the beam direction. Where the surface is more tangential to the beam direction, a more uniform increase in dose is evident from the cast material.

Figure 4 shows the total dose distribution during the treatment measured by the film. The profiles were obtained by taking line profiles through the central three pixels along each film. The doses from the MOSFETs at the positions shown in figure 2 are also shown in figure 4, with their corresponding position numbers. The MOSFET error bars represent the 95% confidence interval of the mean of three measurements using Student's *t*-test. Table 1 shows the percentage increase in skin dose at each measurement location, relative to the dose with no immobilization cast.

In figure 4(a) it is seen that the immobilization cast increased the superior in-field surface dose by 27.3–45.7% and 28.4–62.3% as measured by the film and MOSFET dosimeters, respectively. The MOSFET dose measurements in figure 4(a) agree within error with the dose at corresponding film positions and follow the general trend of increased dose away from the midline and toward the axilla in both cases with and without Orfit. Figure 4(b) shows an increase in central in-field surface dose by 12.1–109.8% and 3.6–44.7% as measured by the film and MOSFET dosimeters, respectively. The high increase at position 5 (109.8%) measured with the film can be attributed to the very high dose gradient at this location which increases the sensitivity to positional variations. The MOSFET-measured doses are slightly less than that measured by the film. Figure 4(c) shows an increase in inferior in-field surface dose by 14.2–23.0% and 30.0–49.4% as measured by the film and MOSFET dosimeters, respectively. In the presence of the Orfit, the MOSFET-measured inferior dose is larger than

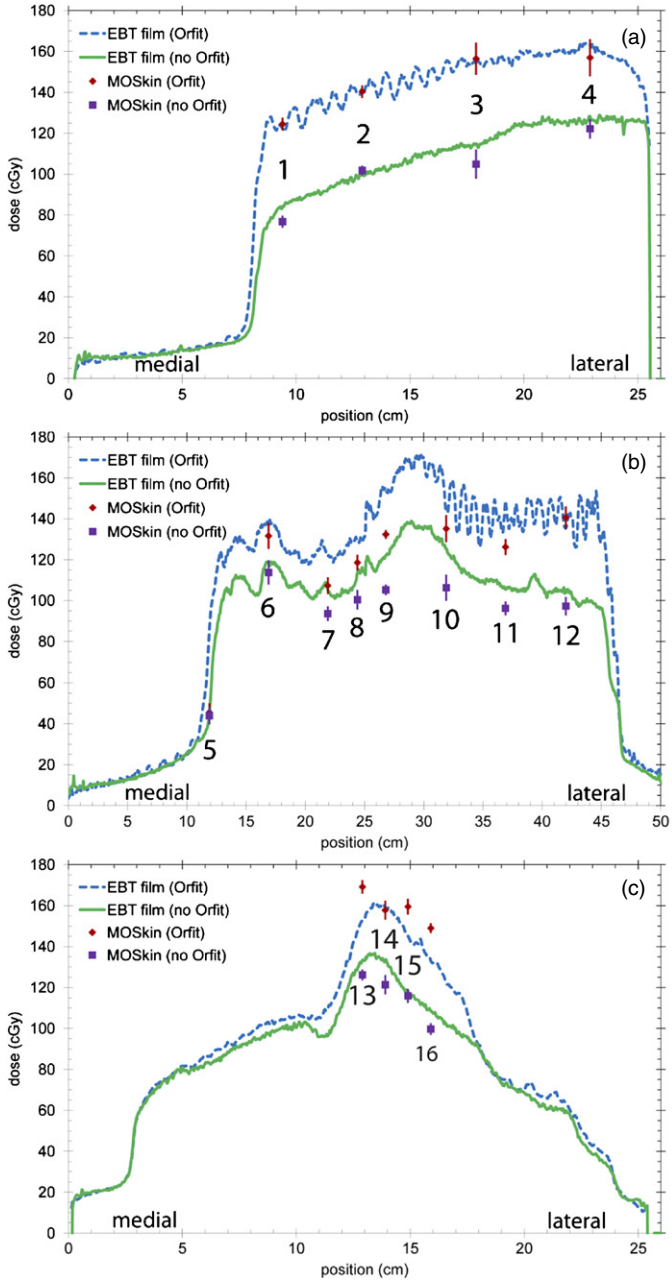

Figure 4. Measured Gafchromic EBT film profiles and MOSFET point dose measurements at the detector locations given in figure 2 for (a) superior film strip and MOSFET positions 1 through 4, (b) central film strip and MOSFET positions 5 through 12 and (c) inferior film strip and MOSFET positions 13 through 16.

the EBT-measured dose, despite a lower WED for the MOSFET compared with Gafchromic EBT film. This is most probably due to error in placement of the MOSFETs possibly medio-

Table 1. Percentage increase in surface dose due to the immobilization cast (relative to no cast) at the 16 measurement locations shown in figure 2.

		% increase in surface dose	
Strip	Position	Gafchromic EBT film	MOSFET
Superior	1	45.7	62.3
	2	41.5	37.8
	3	35.0	49.1
	4	27.3	28.4
Central	5	109.8	3.6
	6	17.3	15.7
	7	13.7	14.6
	8	12.1	18.1
	9	25.3	25.8
	10	14.2	27.2
	11	39.9	31.2
	12	30.2	44.7
Inferior	13	14.2	34.1
	14	20.2	30.0
	15	23.0	37.6
	16	22.5	49.4

laterally but more likely in the superior–inferior direction where a high dose gradient exists (figure 1) and any superior–inferior shift in measurement location would result in a large difference in measured dose.

3.2. The effect of Orfit on entrance/exit dose

In order to understand the contributions of each gantry angle to the surface dose presented in figure 4b, the dose components were split up into the dose delivered from the two gantry angles. This data is presented in figure 5, with the percentage differences in surface dose with the immobilization cast (normalized to no cast) presented in table 2. Figure 5(a) shows the Gafchromic EBT film and MOSFET data from the 135° beam which delivers dose from the lateral to medial beam direction. From approximately 30 to 46 cm is the lateral breast wall where the dosimeters are exposed to the build-up region of this beam (entrance dose). Below 30 cm is the apex of the breast and medial breast wall where the dosimeters are exposed to tangential irradiation and build-down region of the beam (exit dose). In figure 5(a) the Gafchromic EBT film results show that for the lateral wall the Orfit increases the dose (up to 79.5% for film and 78.6% for MOSFET); however for the medial wall the Orfit has minimal effect on the dose (maximum increase of 7.8% for film and 5.4% for MOSFET).

The extra build-up material provided by the Orfit increases the surface dose in the case where the surface dose is due to beam entrance and minimally in the case where the surface dose is due to beam exit. In figure 5(b), which shows the surface dose due to the 311° beam, the Orfit causes the largest increase in surface dose between 12.5 and 30 cm (up to 37.6% for film and 33.4% for MOSFET, ignoring point 5 due to reasons described above) where the beam is incident tangentially to the apex directly on the medial breast wall. The Orfit is also seen to slightly increase the dose (up to 15.7% for film and 22.5% for MOSFET) for the region 30–50 cm where the surface dose is due to the beam exiting the phantom. In

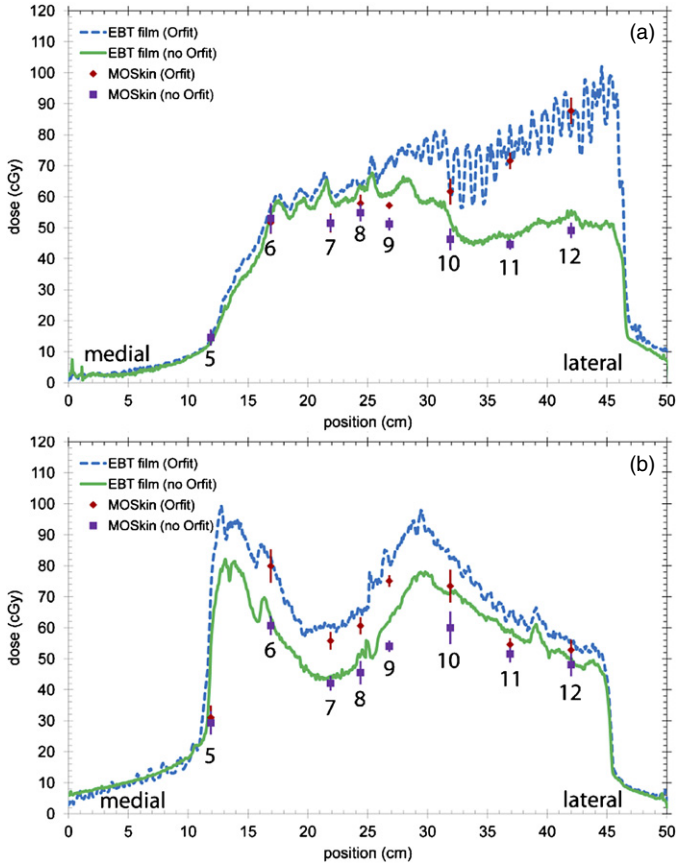

Figure 5. Contribution to surface dose from individual gantry angles for the central film: (a) surface dose from gantry angle 135° and (b) surface dose from gantry angle 311°. The addition of dose from (a) and (b) gives the total treatment dose in figure 4(b).

figure 5(b) there are two clear peaks in the dose profile. The first, occurring at approximately 14 cm, is due to tangential irradiation of the contralateral breast. The second, occurring at approximately 30 cm, is due to tangential irradiation of the target breast. There is a point of minimal dose between the two peaks, occurring at approximately 22.5 cm. This is where the beam is normally incident on the breast surface, therefore the depth of measurement in the Gafchromic EBT film is at its shallowest as seen by individual incident beamlets (surface dose increases with increasing surface angle).

3.3. Variation of surface dose with cast thickness and incident angle

The variation of the MOSFET-measured surface dose with the cast thickness and incident beam angle was measured. Figure 6 shows the surface dose increasing with the increase of beam obliquity. For measurement points under the cast material, the thicker cast material resulted in a larger increase in surface dose compared with the thinner cast material, as expected. Under a gap in the cast material, the thicker cast material results in only very small increases in surface dose. The presence of the cast material results in an approximately 35% to 48%

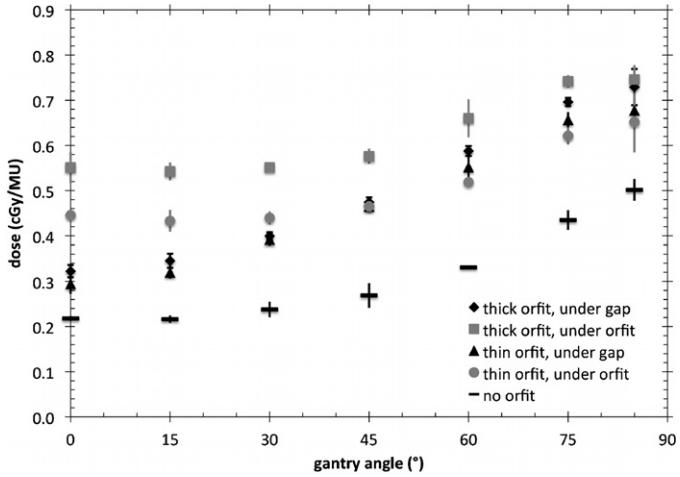

Figure 6. Surface dose variation with the immobilization cast thickness and incident beam angle. The error bars represent 1 standard deviation of the mean of three measurements. The dose is normalized to cGy MU^{-1} where 1 MU = 1 cGy at a depth of 1.5 cm in water for a 10×10 cm^2 6 MV photon field at 100 cm SSD.

Table 2. Percentage increases in surface dose due to the immobilization cast (relative to no cast) along the central strip for the two beams.

		% increase in surface dose	
Gantry angle	Position	Gafchromic EBT film	MOSFET
135°	5	13.93	−0.68
	6	7.84	−2.64
	7	2.84	0.00
	8	0.80	5.46
	9	17.70	11.72
	10	15.16	33.26
	11	79.53	60.54
	12	48.71	78.62
311°	5	120.80	5.80
	6	25.87	31.63
	7	37.61	32.54
	8	29.59	33.41
	9	33.22	38.82
	10	15.73	22.50
	11	10.83	5.81
	12	9.15	9.77

increase in surface dose for the thinner and thicker cast material, respectively, compared with no immobilization cast at 0° even under a gap in the cast. This increases to 51% and 60% increases in surface dose for the thinner and thicker cast material, respectively, at 75°.

4. Discussion

This study utilizes two different radiation detector systems to quantify the effect of an immobilization cast on skin dose in breast radiotherapy. Both the Gafchromic EBT film and MOSFET results show an increase in surface dose as a result of the bolus effect of the cast material. The presence of Orfit stretch-holes can be clearly seen on the Gafchromic EBT film strip in figure 3 and by the modulation in dose measured by the film. It can also be seen that lateral scatter from the Orfit structure surrounding a stretch-hole contributes to the surface dose in the uncovered area of skin. This is evidenced by the dose in a stretch-hole being higher than when the Orfit is not present. Currently it is not understood by what amount larger stretch-holes in the immobilization cast could reduce breast surface dose, while maintaining requisite physical rigidity for immobilization.

It was observed during experimentation that the immobilization cast varied in thickness due to non-uniform stretching over the phantom. This is an unavoidable aspect of using the cast material. How this affected the results during the experiment (dose increase from the Orfit in a given region) is not known given the complexity of both the anthropomorphic phantom geometry and the field arrangement. It was shown that a thicker Orfit increases surface dose where the beam is entering the phantom. It was also observed that the Orfit was not in direct contact with the phantom surface in every region. In particular, the Orfit did not sit perfectly on medial side of the ipsilateral breast and the midline. This could possibly be the reason why the same cross-hatched patterning is not observed in this region. The elevation of the cast material from the surface would allow greater scattering and dispersion of secondary photons and electrons set in motion within the cast structure by the time it reached the phantom surface.

Under calibration irradiation conditions at the surface, MOSFETs measure dose at 70 μm WED and Gafchromic EBT film at 153 μm WED. In ideal, normally incident radiation the MOSFETs measure a lower dose than film as a result of the different WED. Surface dose in breast radiotherapy is by contrast much more complicated. The placements of MOSFETs in this experiment experienced highly oblique beam angles, multiple field sizes, position variation within large fields, and varying backscatter conditions. All MOSFETs were placed face up on the phantom surface throughout measurements and the measurement conditions varied from 0–360° angle of incidence. That is, the MOSFETs were measuring both the contribution of entrance and exit dose to the total surface dose. Keeping the MOSFETs face up regardless of beam orientation results in a water equivalent material thickness of 70 μm above the measurement depth for either build-up or build-down, depending on which beam angle is being used.

A comparison between the MOSFET- and Gafchromic EBT film-measured doses revealed varying levels of agreement. This is due to the build-up dose gradient changing depending on the beamÕs' angle of incidence. As the angle of incidence increases, that is, the beam becomes more tangential to the phantom surface, the build-up dose gradient decreases. Therefore the differences in doses measured at 70 μm and 153 μm WED vary depending on the angle of incidence. This is observed in the comparison between the MOSFET- and Gafchromic EBT film-measured doses. A further complication in these comparisons arises due to the MOSFET being a point detector and the film being a 2D detector. The small MOSFET measurement volume makes the measured dose susceptible to the varying thicknesses of the build-up cast material.

Two trends are evident from the results. The first is that the beam obliquity has a large effect on the surface dose. The highest surface dose was observed where the beam was more tangential to the surface. This is in agreement with previous studies (Dogan and Glasgow 2003, Hsu *et al* 2008, Quach *et al* 2000). The second is that the presence of the immobilization

cast increased the surface dose by varying amounts. The highest increase in surface dose was observed at beam entrance locations. At tangential beam and beam exit locations the immobilization cast had a reduced effect on the surface dose. This corresponds well to the results presented by Hsu *et al* (2008). The study by Lee *et al* (2002) suggests that for head and neck radiotherapy, skin reactions were caused by a combination of the use of tangential beams, use of an immobilization cast and inclusion of the skin in the target volume. The increases in surface dose due to the immobilization cast were on average 18%, which suggests that the surface dose increases found in this study would contribute to an increased chance of skin side effects.

An analysis of the variation of the surface dose with varying incident beam angle and cast thickness reveals that even when there is no cast material above a measurement point (i.e. in a gap in the cast), the surface dose is still increased by 35% to 60%. With cast material above the measurement point the dose increased to up to 55% of the dose at $d_{\max}$ (1.5 cm), which is similar to the result found by Hadley *et al* (2005) of 61%. The surface dose increased with increasing beam obliquity and thickness of cast material (and consequently smaller gaps in the cast). Chiu-Tsao and Chan (2010) also found with Gafchromic EBT film that the average surface dose increased both under gaps and struts in an immobilization cast. This suggests that to reduce the increase in surface dose due to an immobilization cast, the cast should be stretched to be as thin as possible with as large air gaps as possible whilst still retaining enough structural integrity to achieve immobilization.

Both MOSFET and Gafchromic EBT film were found to be suitable tools for surface dosimetry in breast cancer treatment. The presented data demonstrates good agreement between the two detectors within the discussed expected limitations of dose measurement in such a complex geometry. The advantages of the MOSFET detector system are its ability for real-time and high spatial resolution surface dosimetry, which allows quick analysis of the contribution of individual beams and segments to the surface dose. The Gafchromic EBT film also provided excellent spatial resolution and allowed for 2D surface dose maps to be presented, highlighting the effect of the immobilization cast on entrance and exit surface dose. The doses measured by each detector are useful; while EBT measures dose in a volume 40 μm thick centered at 153 μm WED, the MO*Skin* measures dose exactly at 70 μm WED. Comparison of these doses can be useful clinically for determining the dose gradient near the surface. In addition, skin toxicity can occur due to radiation damage at different depths in the skin, such as the skin epidermis and basal layer. The use of two detectors is a step toward a more complete prediction of radiation damage to the different components of the skin.

5. Conclusion

The use of an immobilization cast caused significant increases in surface dose to the breast phantom as measured by two surface dose detectors. The effect of the cast depended on whether the surface dose was entrance or exit dose, with the greatest increases in surface doses observed in the former case. The increase in surface dose must be considered with any clinical advantages that could be obtained by using a thermoplastic immobilization cast for breast immobilization.

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