



Radiation Dose to the Contralateral Breast and Effectiveness of Superflab in Dose Reduction during Treatment of Breast Cancer by Cobalt-60 External Beam

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Abstract

Radiation therapy for breast cancer inevitably results in scattered dose to contralateral breast. Breast tissues being highly sensitive to ionizing radiations, the chance of the contralateral breast developing second cancer after radiation therapy is high. This study investigated dose to contralateral breast and its reduction by superflab during the course of breast cancer radiation therapy. A thorax breast phantom constructed from tissue-equivalent materials and diodes (type IVD² 1137) were used to measure surface doses to the contralateral breast. The mean doses received by the contralateral breast were 2.2% and 7.1% of the prescribed dose of 200 cGy for $5 \times 5 \text{ cm}^2$ and $10 \times 10 \text{ cm}^2$ field sizes, respectively. These dose values were mostly comparable to and slightly higher than the dose values reported in the literature. The average reduction of dose to contralateral breast with superflab was 65.6%, in the range of 49 to 100%. The differences between doses with and without superflab were significant at $p < 0.05$. The superflab was more effective for larger field sizes than smaller. In view of this enormous advantage in dose reduction, this approach should clinically be tested for routine applications in breast cancer radiation therapy at hospitals in Tanzania.

Keywords: Breast cancer, contralateral breast dose, secondary cancer, superflab.

Introduction

Recent studies have shown that cervical cancer is the most prevalent followed by breast cancer in Tanzania (Amour et al. 2019). According to GLOBOCAN 2012, breast cancer incidence and mortality were projected in 2012 to have increased by 82% and 80%, respectively in 2030 (Ferlay et al. 2012). Implicit in the predictions is rapid increase of incidences and low survival of breast cancer patients. Efforts have been and continue to be

made to reduce both incidences and mortality rates. Increase of public awareness of risk factors and breast cancer screening are among the efforts being made to reduce the burdens of breast cancer in Tanzania (Ngoma et al. 2015, TBHCA 2017). Additional efforts are being made to increase breast cancer cure rates by improved dose delivery accuracy during radiation therapy (Yusuph et al. 2016).

While dose delivery accuracy is important, it may undermine the benefits of cancer

treatments, if protection of contralateral breast is not taken. Radiation dose to the contralateral breast during radiation treatment of breast cancer has been of concern globally. The concern originates from the fact that, when considering the stochastic effects, even small radiation doses have some risks (ICRP 2009). Breast tissues being highly sensitive to ionizing radiations, dose to the contralateral breast has been implicated in the risks of second cancer in longer follow-ups (Hooning et al. 2008). Thus clinically unjustified and avoidable dose to contralateral breast may unnecessarily lead to secondary cancer. Like in many African countries, in Tanzania breast cancer patients receive radiation treatments without protection measures taken to contralateral breast. However, little has been known of the magnitude of doses to the contralateral breast in practice. Lack of this information would be interpreted as efforts to reduce cancer incidences attributed to radiation therapy procedures have not been accorded the attention they deserve in Tanzania. Therefore, the purpose of this study was to investigate doses to the contralateral breast and their reduction by superflab. Such studies would be important to identify effective practices for intervention to reduce dose received by the contralateral breast and consequently reduction of breast cancer radiation treatment related morbidity in Tanzania.

Materials and Methods

Since it is unethical to perform experimental investigations directly on patients, estimation of doses to the contralateral breast must be obtained from phantom measurements. However, for dose estimation in phantom to be comparable to that measured in the patients, phantom materials must be tissue-equivalent. Water is one of the tissue-equivalent materials because its radiation absorption and scattering properties closely resemble that of soft tissue. Thus, water has been extensively used as phantom material in various radiation dosimetric studies (Winslow et al. 2009). However, being liquid at room

temperature, water cannot be used in construction of phantom with shapes and /or sizes of patients taken into account. Although there are commercially available anthropomorphic RANDO phantoms for this purpose, these phantoms are often expensive and not readily accessible to researchers in many cancer centres in developing countries like Tanzania. In such situations, tissue equivalent materials that can be moulded into desirable shapes and sizes of patients are used in various patient dose estimation studies. The cheaper and highly accessible paraffin wax being sufficiently soft and easy to mould into desired shapes and/or sizes has been used in various patient dose estimation studies (Hasanzadeh and Abedelahi 2011, Senthilkumar 2014). For these reasons, paraffin wax was used as breast tissue equivalent substitute.

Construction of phantom

The construction of the shape and size from 35 kg paraffin wax involved several steps; firstly, paraffin wax was subjected to heat until it became sufficiently molten. Secondly, the molten paraffin wax was filled in a thorax breast plastic shell and allowed to solidify by cooling for about 120 minutes. Thirdly, after the melted wax had cooled, the phantom and the thorax breast plastic shell were separated. Additional modifications were made so as to obtain a phantom with smooth surface to reduce beam scattering. The thorax breast phantom resulted from the procedures is presented in Figure 1. Using water displacement method, the average volume of the breasts of a phantom was found to be about 680 cm³.



Figure 1: Photograph showing a thorax breast phantom constructed from paraffin wax.

Diode calibration and linearity

In practice, a diode calibrated for the photon energy is used and linearity established for a specified range of dose. As recommended, diodes (Model IVD² 1137, manufactured by Sun Nuclear Corporation, Melbourne, USA) for measurements of doses were calibrated using the protocols for calibration of dosimeters described in the IAEA Technical Report Series No. 469 (IAEA 2009). In this report, calibration is based on comparison between the measured dose to water with a reference ion chamber and a user dosimeter to be calibrated. Using this protocol, the diodes were calibrated against a calibrated farmer TM30002 ionization chamber (0.6 cc) connected to a UNIDOS electrometer, PTW-Model 1100-Freiburg. The calibration of the ionization chamber is traceable to the *Bureaus International des Poids et Mesures* (BIPM) through IAEA. The calibration measurements were performed in a $50 \times 50 \times 50 \text{ cm}^3$ PTW water phantom in reference conditions (SSD = 80 cm, field size of $10 \times 10 \text{ cm}^2$, gantry of 90 degree and 0.5 cm depth). As shown in the calibration set-up in Figure 2, the diodes were placed on the surface of the water phantom, while the ionization chamber was placed at the

reference depth of maximum dose ($d_m = 0.5 \text{ cm}$) at the axis using the SSD technique. The machine was then set up to deliver a specified dose of 1 Gy using $10 \times 10 \text{ cm}^2$ field size. The absorbed (measured) dose (D) to water with the diode, at the reference depth in a beam of quality Q was obtained using Equation (1) (Alahverdi et al. 2008).

$$D = M_Q \times F_{cal} \times F_{corr} \quad (1)$$

where: M_Q is the diode reading in a beam of quality Q, F_{cal} is the calibration factor which gives the ratio of the absorbed dose measured with the ionization chamber to the diode reading and F_{corr} is the correction factor for energy, which for cobalt-60 beam is equal to 1.

Once the energy calibration factors for diodes 1 and 2 are stored in the memory of the detector's pod for the specific channel for which the detector was calibrated, these calibration factors become available in the subsequent measurements.

While in the same experimental settings, sets of measurements for validation of the diode calibrations were obtained by irradiating the diodes with a known dose of 100 cGy at dose rate, $Dr(t) = 186.17 \text{ cGy/min}$ using $10 \times 10 \text{ cm}^2$ field size at 80 cm SSD (source to skin distance). The doses recorded by diode 1 and 2 with respect to this dose were 103.1 cGy and 102.7 cGy, respectively. The reproducibility of 0.17% and 0.12% for diode 1 and 2, respectively for five repeated measurements were comparable to the specified reproducibility of $\pm 0.2\%$ ($\pm 0.1 \text{ cGy}$) (IVD SolutionsTM User's Operational Manual).

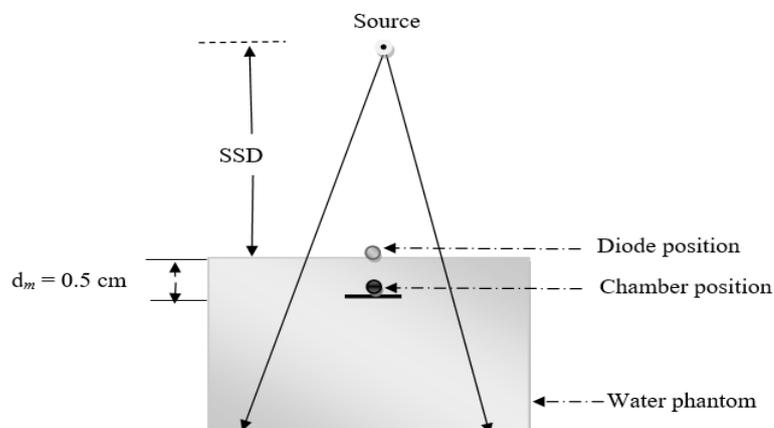


Figure 2: Set-up for diode calibration against a reference ion chamber.

As pointed out earlier, dose response linearity is a good indicator that a diode is accurate in dose measurements. In this case, diodes were irradiated with prescribed doses expected to be measured ranging from 0.5 to 2.4 Gy at the interval of 0.1 Gy using field size of $10 \times 10 \text{ cm}^2$ at 80 cm SSD. These measurements were repeated after replacing the diodes with a calibrated farmer TM30002 ionization chamber (0.6 cc) connected to a UNIDOS electrometer, PTW-Model 1100-

Freiburg. The response of calibrated diodes and ionization chamber as a function of dose is presented in Figure 3. The diodes displayed an excellent linear dose response ($R^2 = 0.999$) with respect to the measured dose from 0.5 to 2.4 Gy. From these observations, it is shown that the response of diodes to dose is not only linear, but it is also accurate and therefore suitable for dose measurements.

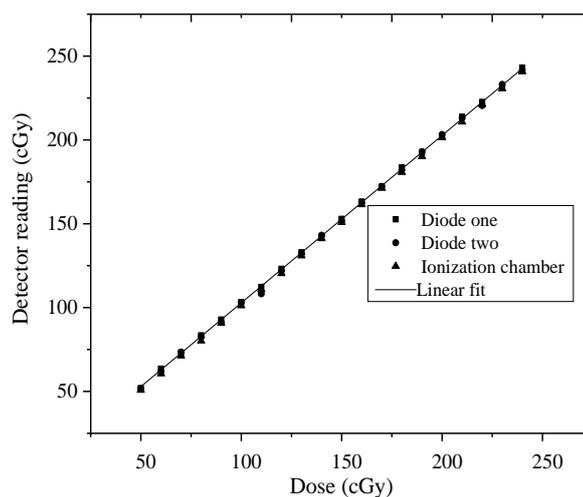


Figure 3: Response of ionization chamber and calibrated diodes as a function of dose at 80 cm SSD and $10 \times 10 \text{ cm}^2$ field size.

Phantom set-up and irradiation technique

To investigate the influence of breast shape and field size on dose to the contralateral breast, the phantom shown in Figure 4 was used. In order to take into account the influence of breast shape on dose, it was necessary to make measurements at different positions on the contralateral breast. To implement this requirement, different positions (points) were made along three medial-lateral traces A, B and C marked on the surface of contralateral breast. Trace A was selected to be at the same level of the central axis of the tangential fields and passed through the nipple, while traces B and C were at distance 3 cm anterior and posterior of trace A, respectively. Five points on trace A for dose determination were made and marked by numbers 1, 2, 3, 4 and 5 shown in Figure 4. The points were at distances 3, 6, 9, 12 and 15 cm from midline of the phantom. Five points at the same distances from midline of the phantom were also made on traces B and C (not shown in Figure 4).

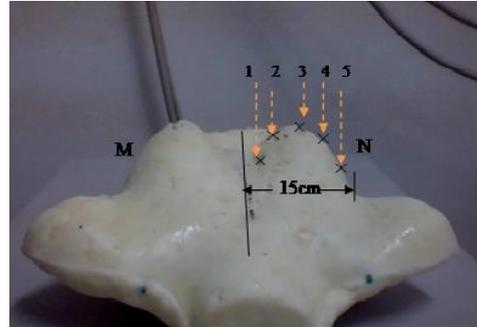


Figure 4: Phantom and diodes set-up for measurements of doses to the contralateral breast (N). The mark x indicates points for dose determination, while M is for an infected breast.

In order to simulate clinical condition, the phantom was then placed in supine position on the treatment table exactly in the same way as a patient would be positioned when undergoing breast cancer radiation treatments. As required in the conventional two-tangential beams technique, the gantry was positioned at lateral field of 304° (Figure 5a) and medial field of 126° (Figure 5b) each at 80 cm SSD. The technique was used to irradiate a target tumor volume (infected breast) imagined to be covered by different field sizes varying from 5 × 5 cm² to 10 × 10 cm². Using this phantom and beam set-up, two sets of dose measurements to the contralateral breast were performed, one with and the other without superflab.



(a)



(b)

Figure 5: Photograph showing phantom set-up on Theratron Equinox cobalt-60; (a) lateral field, and (b) medial field.

Determination of dose to the contralateral breast without superflab

In this set of measurements, doses to the contralateral breast were measured at distances 3, 6, 9, 12 and 15 cm from the midline on traces A, B and C for different photon beam field sizes. The field sizes used were increased by 1 cm from $5 \times 5 \text{ cm}^2$ to $10 \times 10 \text{ cm}^2$. Since only two diodes were available, for each field size, several irradiations were made with the diodes placed at different positions as follows: Diode one was placed at 3 cm from midline (position 1) and diode two at 6 cm from midline (position 2) on trace A shown in Figure 4. The diodes were then shifted to measure doses at remaining points 3, 4 and 5. In all dose measurements, the directional dependence of the diodes relative to the beam was taken into consideration during the placement of diodes. In all irradiation fields, the medial and lateral prescribed dose to the breast tumor was 100 cGy. The same procedures were used for dose determination on traces B and C for field sizes that varied from $5 \times 5 \text{ cm}^2$ to $10 \times 10 \text{ cm}^2$. Since the dose at each point was from two opposing fields, the dose at each point on the contralateral breast was the sum of the dose from the lateral and medial fields.

Determination of dose to the contralateral breast with superflab

In this set of measurements, doses were measured with superflab (SBM-3305, 0.5 cm thick) placed over the diodes taped on surface of the contralateral breast. Since the influence of the superflab on dose reduction is relative, it was not necessary to duplicate all dose measurements of traces A, B and C described earlier. This was implemented by selecting the trace and field with highest dose contributions to the contralateral breast. Using this criteria, trace A and medial field were selected for dose determination to the contralateral breast with superflab. The superflab was placed over the diodes placed at distances 3, 6, 9, 12 and 15 cm from phantom midline on trace A and medial dose measurements were made using intermediate field size of $7 \times 7 \text{ cm}^2$. The

influence of photon beam field size on the effectiveness of superflab was investigated by making dose measurement at the nipple for field sizes varying from $5 \times 5 \text{ cm}^2$ to $10 \times 10 \text{ cm}^2$ described earlier. The analysis of paired-samples *t*-test ($p < 0.05$), 95% confidence level) was finally performed to determine whether the measured doses with and without superflab were significantly different.

Results and Discussion

Doses to the contralateral breast

The sum of the doses from the medial and lateral fields at each position for trace A on the contralateral breast received from 200 cGy prescribed dose to the tumor were plotted in Figure 6. The sum of doses at various distances from midline of the phantom for traces B and C were also plotted in Figures 7 and 8, respectively. As expected, the doses to the contralateral breast from the figures showed that, the larger the field size the higher the dose to the contralateral breast. Implicit in this observation is that, shielding of the contralateral breast is more important from radiation protection point of view, when treating breast cancer using large field sizes. It was further observed that, the contralateral breast dose from the medial field was about 2 folds higher than that from the lateral field (data not shown). This was expected because the medial beam is closer to the contralateral breast compared to the lateral beam which is farther away.

Another important observation from Figures 6, 7 and 8 is that, doses to the contralateral breast for traces A, B and C decreased with increase in distance from the midline. Similar patterns of doses decreasing from medial to lateral directions have been reported in the literature (Solanki et al. 2017). This trend is caused by the fact that the farther away the lateral part of the contralateral breast is from the midline, the smaller the dose. Therefore, the highest dose at distance 3 cm from midline is expected because it is nearest to the treatment beam. The observed fluctuations of doses from this trend could be

attributed to the influence of shape variations of contralateral breast on dose. For the shape used in this study (see Figure 1), there was an increased dose at protruding regions of the contralateral breast regardless of photon beam field size. For trace A, the protruding region with the highest dose fluctuation coincided with the nipple (9 cm from phantom midline). The doses at distance 9 cm from midline were 3.8% and 11.7% of the prescribed dose for $5 \times 5 \text{ cm}^2$ and $10 \times 10 \text{ cm}^2$ field sizes, respectively. It was further observed that, the doses at different distances from midline for trace A which was at the same level of the central axis of the tangential fields and passed through the nipple, were higher than the doses on traces B and C for the same distances irrespective of the field sizes. Implicit in these observations is that, the benefit of shielding the contralateral is dependent of the shape of the breast. Since the

protruding regions for traces B and C are not as well marked as on trace A, the causes of dose fluctuations observed on traces B and C are not easy to explain. While the influence of breast shape on shielding is important, further studies should be done to establish breast shape parameters relevant to dose fluctuations. From this study, effective shielding of the contralateral breast requires knowledge of breast shape to identify region which would receive high doses during breast cancer treatments. However, since breast shapes are dependent on many variables including age and reproductive factors, experimental determination of relevant variables for shielding would be difficult to implement. Thus, it would be necessary to obtain the required parameters by Monte Carlo simulation.

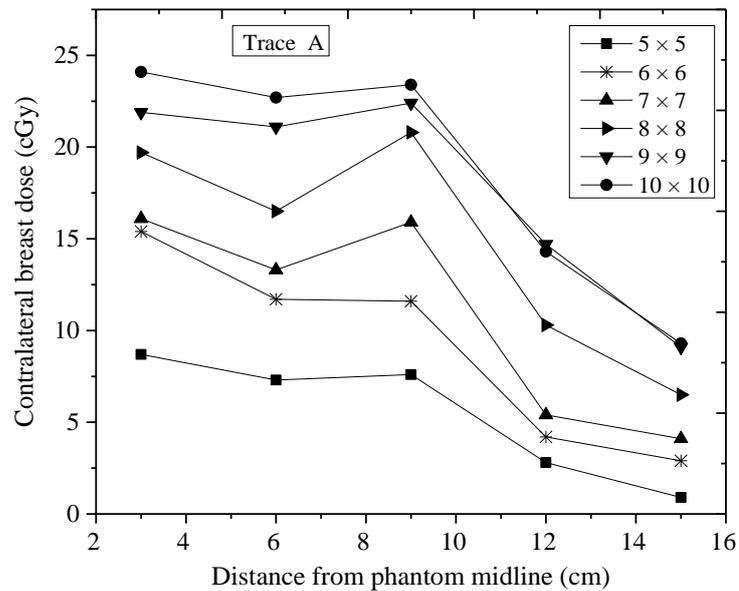


Figure 6: Dose as a function of distance from midline for different field sizes for trace A.

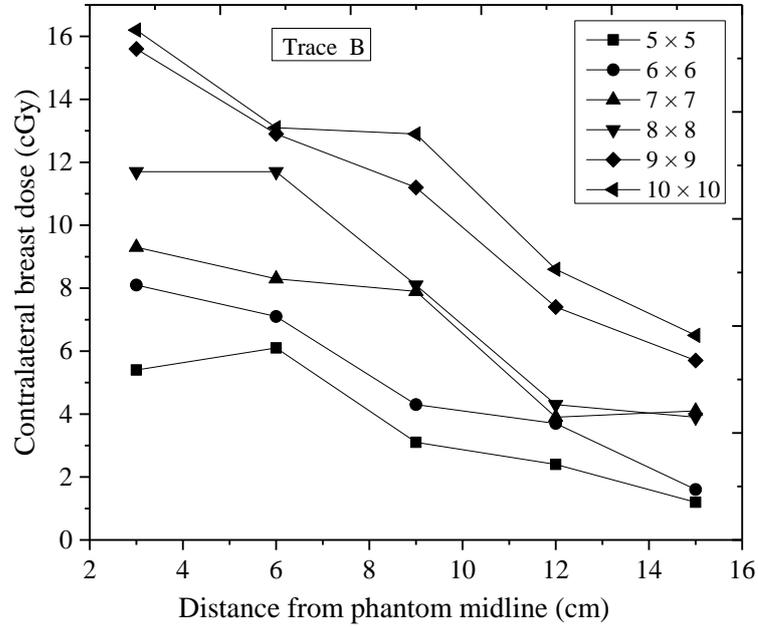


Figure 7: Dose as a function distance from midline for different field sizes for trace B.

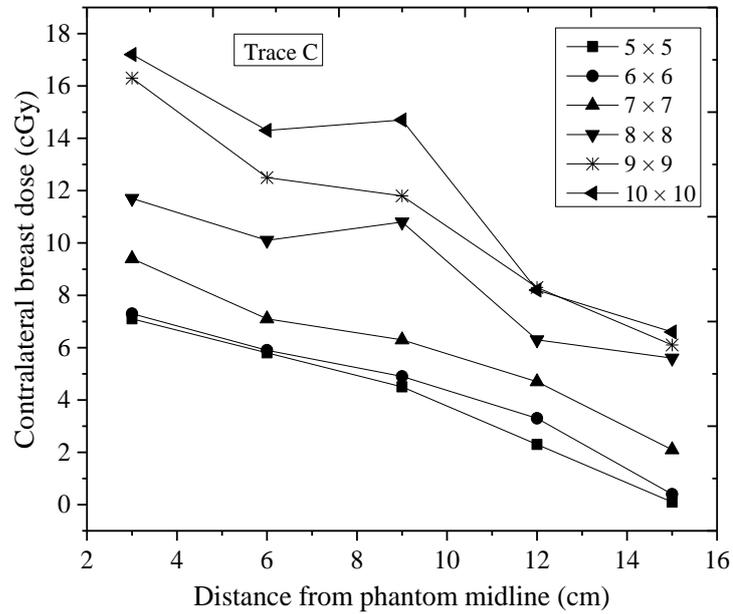


Figure 8: Dose as a function of distance from midline for different field sizes for trace C.

Of interest in this study was the amount of dose received by the whole contralateral breast from the prescribed dose to the tumor during the course of radiation therapy. As described

earlier, the amount of the dose to the contralateral breast is dependent on the shape and size of the breast. For the shape and size of the breast used in this study, the average dose to the contralateral breast received from single dose fraction of 200 cGy prescribed dose to the tumor without superflab was 4.4 ± 2.7 cGy (2.2% of the prescribed dose) for 5×5 cm² field size and 14.1 ± 5.9 cGy (7.1% of the prescribed dose) for 10×10 cm² photon beam field size.

In practice, for curative intervention of breast cancer, a total dose of 5000 cGy is administered at 200 cGy per fraction for 25 dose fractions at interval of 3 days. This implies that the total dose to the contralateral breast received from 5000 cGy prescribed dose to the tumor was found to be 110.0 cGy and 352.3 cGy for 5×5 cm² and 10×10 cm² field size, respectively. These results were mostly comparable to and slightly higher than the dose values reported in some studies (Chougule 2007, Johansen et al. 2007). On the other hand, the observed dose values to the contralateral breast in this study were higher by a factor of up to 2 relative to that reported in other studies (Alzoubi et al. 2010). This variation could be attributed to the differences in beam quality, shape of the breast and the closeness of tangential fields to contralateral breast as it varies. For instance, the dose values reported by Alzoubi et al. (2010) were measured from a Rando Alderson phantom using LINAC photon beam, while in this study measurements of dose were made from an in-house constructed phantom using cobalt-60 photon beam. As reported in the literature, the problem of increased doses to the contralateral breast is more pronounced for cobalt-60 photon beam

than LINAC (Faaruq et al. 2009). This could be attributed to the fact that cobalt-60 photon beam has larger penumbra than LINAC (Ravichandran 2009). Although the observed doses reported in this study were slightly comparable to other studies, optimisation of protection and safety requires the exposure to normal tissues be kept as low as reasonably achievable (ALARA) while delivering the required dose to the planned target volume. Therefore, the effectiveness of 0.5 cm thick superflab for reduction of dose to the contralateral breast during radiation therapy for breast cancer using cobalt-60 external beam was demonstrated.

Dose to the contralateral breast with superflab

Doses received by the contralateral breast from 100 cGy prescribed dose to the tumor at distances 3, 6, 9, 12 and 15 cm from midline on trace A with and without superflab along with percentage reduction are presented in Table 1. From the table, the doses with and without superflab decreased with increasing distance from the midline with imposed fluctuation at 9 cm from midline as observed earlier. It is also observed from the table that, without superflab the doses at positions 3 to 9 cm from the midline were about 8 to 10% of the prescribed dose. The doses at positions 12 and 15 cm from the midline were approximately 3% of the prescribed dose and comparable. Use of superflab to shield the contralateral breast has enabled dose reduction at distances 3, 6 and 9 cm from midline by 53%, 62% and 54%, respectively. On the other hand, the reduction of dose at positions 12 and 15 cm from midline were 97% and 100%, respectively.

Table 1: Doses received by the contralateral breast from 100 cGy prescribed dose to the tumor with and without superflab at different distances from midline.

Distance from midline (cm)	Doses at different distances from midline (cGy)		
	Without superflab ^a	With superflab ^b	% dose reduction*
3	10.3	4.9	52.9
6	8.0	3.1	61.6
9	10.1	4.6	54.4
12	3.4	0.1	92.2
15	2.7	0	100

$$* \frac{(a-b)}{a} \times 100\%$$

In view of these observations, it is evident that the efficiency of superflab in dose reduction is small at distance 3 cm from the midline. The low dose reduction associated with this position could be attributed to the fact that 3 cm from the midline is nearest to the treatment beam. Conversely, the efficiency of superflab is highest at 12 and 15 cm from midline because these positions are farther away from the medial field. From these observations, while it appears that the reduction of dose with superflab in terms of percentage dose reduction is most effective at large distance from midline, this cannot only be used to assess the effectiveness of superflab because the dose received at large distances from

midline are relatively small. For this reason, the doses to the contralateral breast with superflab at different distances from the midline compared to that without superflab presented in Table 1 were plotted in Figure 9. From the figure, it is appears that the superflab is more beneficial at smaller distance than larger distance from midline. This benefit is shown by the wide gap between dose with and without superflab at distance 3 cm from midline compared to that at distance 15 cm from the midline. In addition, the results of the *t*-test showed that the measured doses with and without superflab were significantly different ($p = 0.002$).

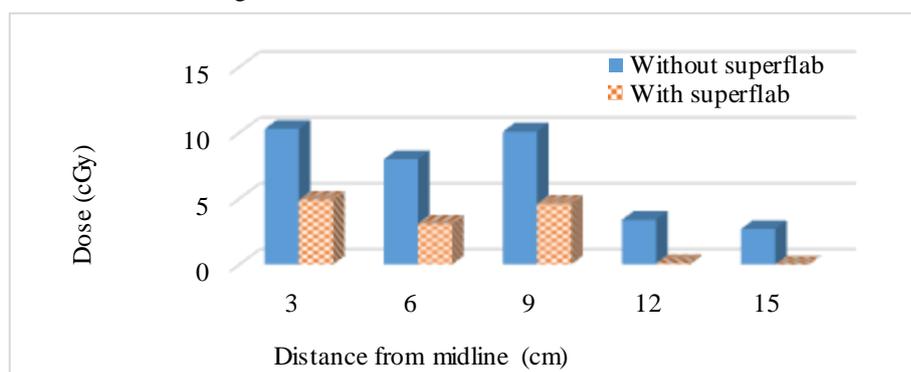


Figure 9: Dose at various distances from the midline with and without superflab.

The doses received by the nipple of the contralateral breast from 100 cGy prescribed dose to the tumor at different photon beam field sizes are presented in Table 2. From the table, the dose for $10 \times 10 \text{ cm}^2$ field size was

almost 3 folds the dose received by the $5 \times 5 \text{ cm}^2$ field size. From the table, by examining the percentage dose reduction, it appears that, use of superflab was more efficient in dose reduction for smaller field size than larger field

size. This is indicated by 73.6% and 49% dose reductions for $5 \times 5 \text{ cm}^2$ and $10 \times 10 \text{ cm}^2$, respectively. However, from the radiation protection point of view, this is not the case. This is because, since radiation harm is proportional to dose, the highest reduction was achieved at points which received the least dose. Although it appears from the percentage dose reduction that the superflab is most effective at small field size, in absolute dose

values, the superflab is more beneficial for larger field size than smaller. This is shown, for instance, by the higher dose reduction of 7 cGy at $10 \times 10 \text{ cm}^2$ than 3.9 cGy dose reduction at $5 \times 5 \text{ cm}^2$. From these results, it can be concluded that the deviation between absolute dose values with and without superflab is a better parameter for assessing the effectiveness of superflab in dose reduction than the percentage dose reduction.

Table 2: Doses received by the nipple of contralateral breast from 100 cGy prescribed dose to the tumor for different field sizes along with percentage reduction.

Field size (cm ²)	Doses at the nipple for different field sizes (cGy)		
	Without superflab	With superflab	% dose reduction
5×5	5.3	1.4	73.6
6×6	7.9	2.7	65.8
7×7	10.1	3.9	61.4
8×8	13.4	5.5	59
9×9	13.9	6.7	51.8
10×10	14.3	7.3	49

Figure 10 shows the measured doses received by the nipple from prescribed dose to the tumor with and without superflab for different field sizes varying from $5 \times 5 \text{ cm}^2$ to $10 \times 10 \text{ cm}^2$. From the figure, it is also evident that the superflab is more beneficial for larger field size

than smaller. This is shown by the wider gap for $10 \times 10 \text{ cm}^2$ field between dose with and without superflab size than for at $5 \times 5 \text{ cm}^2$. From this observation, it is evident that the need to use superflab is more advantageous for larger field sizes than smaller.

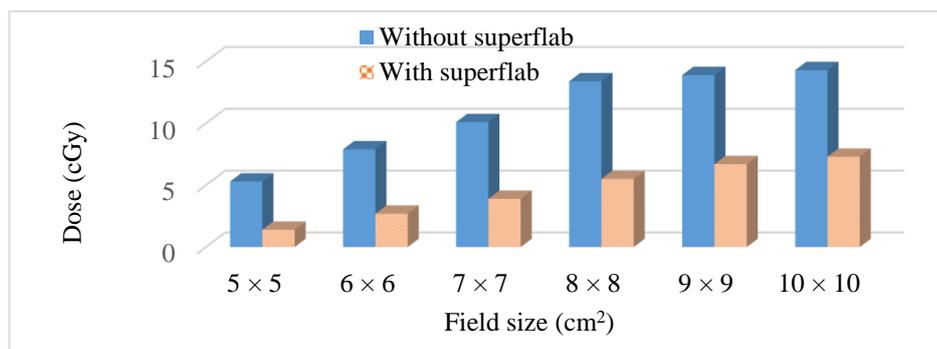


Figure 10: Dose at the nipple measured with and without superflab for different field sizes.

In addition, the results of the *t*-test at $p < 0.05$ showed that the measured doses at the nipple with and without superflab for different field sizes were significantly different $p = 0.0001$. In view of these results and similar experiences

reported in some studies (Solanki et al. 2017), it is evident that the doses to the contralateral breast could be reduced significantly by the use superflab. Therefore, the reduction of dose achieved in this study can also imply effective

dose reduction to patients undergoing typical breast cancer radiation therapy procedures in Tanzania.

Conclusion

External beam radiation therapy will unquestionably continue to play a key role in the curative intervention of breast cancer in Tanzania. However, clinically unjustified and avoidable dose to the contralateral breast during the course of radiation therapy may unnecessarily lead to radiation induced contralateral breast cancer. In view of this risk concern, there is a need to investigate dose to the contralateral and identify effective practices for intervention to reduce such doses as low as reasonably achievable. This study has demonstrated that size and closeness of the contralateral breast with medial tangential field has direct impacts on doses to the contralateral breast. It was observed that the dose to contralateral breast from the medial field was higher than the lateral field. Implicit in this observation is that, there is a need to shield the contralateral breast for the medial field than the lateral. However, effective shielding of contralateral breast would require knowledge of breast shape to identify region which would receive the highest doses. Since breast shape is dependent on many variables, Monte Carlo simulation for determination of the parameters relevant for shielding is recommended. This study has also demonstrated that the dose to contralateral breast could significantly be reduced by the use of superflab. The dose reduction to the contralateral breast by superflab was more effective for larger field sizes than smaller. In view of these benefits in dose reduction, it is therefore concluded that significant potentials of contralateral breast dose reduction exist and the need for radiation therapy departments to pursue dose reduction is evident. However, successful implementation of this approach in clinical practice for routine application in breast radiation treatment requires clinical studies/testing at hospitals in Tanzania.

Conflict of interest: The authors declare that they have no competing interests.

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