*Original Article*

Indian Journal of Cancer Education and Research
Volume 7 Number 2, July - December 2019
DOI: http://dx.doi.org/10.21088/ijcer.2321.9815.7219.2

# To Study the Dose to Skin in Tangential Field without and with Thermoplastic Sheet and Additional Bolus in Post-mastectomy Patients

**Anil Sarolkar[1], Asmita Kulshrestra[2], Shashank N Singh[3], Surabh Karnawat[4], Priyusha Bagdare[5], Virendra Bhandari[6]**

**Author's Affiliation:** [1]Asssociate Professor, [2,3,4]Registrar, [5]Medical Physicist, [6]Professor, Department of Radiation Oncology, Sri Aurobindo Medical College & PG Institute, Indore, Madhya Pradesh 453555, India.

**Corresponding Author: Virendra Bhandari,** Professor, Department of Radiation Oncology, Sri Aurobindo Medical College & PG Institute, Indore, Madhya Pradesh 453555, India.

**Email:** virencancer@yahoo.co.in

**Received on** 31.01.2019, **Accepted on** 16.04.2019

**Abstract**

*Introduction:* Breast cancer poses a major health concern due to its burden on women worldwide being the most common cancer. Postmastectomy radiation therapy (PMRT) forms an integral component in both breast conservation and patients to reduce the loco-regional recurrence and mortality rate. *Aim:* This study was done to analyze the dosimetric parameters to skin over tangential field with and without thermoplastic sheet and with additional bolus in postmastectomy breast cancer patients. *Material and methods:* This study conducted from January 2017 to June 2018 in 20 postmastectomy recruited patients treated by radiotherapy using field-in-field (FIF) by three dimensional conformal radiotherapy (3D-CRT) technique along with planning by tangential fields and application of thermoplastic sheet was used togenerate plans for the patients in all the three arms with same location chosen for all the depth dose profiles and compared for the dosimetric parameters. *Results:* The PTV coverage was significantly higher in plans with thermoplastic sheet with additional bolus followed by higher in plans for thermoplastic sheet ($p$-value <0.001) than in without thermoplastic sheet. The hot spot in the plans with thermoplastic sheet was significantly lesser ($p$-value <0.001) as compared to that in the other two plans. The depth differences for both 90% and 95% doses in the two plans of with and without thermoplastic sheet was statistically highly significant ($p$-value <0.001). The mean dose at 0.1 cm from the skin surface in the arm with thermoplastic sheet was significantly higher ($p$-value < 0.001) than without the thermoplastic sheet. In all the plans with thermoplastic sheet with additional bolus whole skin in the treatment area was well covered with 100% dose. *Conclusion:* Thermoplastic sheet itself acts as a bolus to the chest wall surface for treatment planning ensuring homogenous dose distribution by achieving the required dose on surface along with adequate coverage of dermal lymphatics and postmastectomy scar thus reflecting an effective treatment response with minimal morbidityin patients of carcinoma of breast.Treating the patient without bolus on chest wall reduces the surface dose which is much smaller than that with bolus leading to a limited dose rate, thus a small thickness of the bolus material will lead to a significant increase in the surface dose.

**Keywords:** Breast cancer; Postmastectomy radiotherapy (PMRT); Thermoplastic sheet; Skin dose; Bolus material; Surface dose.

**How to cite this article:**

Sarolkar Anil, Asmita Kulshrestra, Shashank N Singh *et al*. To Study the Dose to Skin in Tangential Field without and with Thermoplastic Sheet and Additional Bolus in Post-mastectomy Patients. Indian J Canc Educ Res. 2019;7(2):55-65.

## Introduction

Breast cancer poses a major health concern due to its burden on women worldwide and accounting for major part of cancer related mortality in the female population. According to surveillance, epidemiology and end results (SEER) program in 2018, an estimated 2,66,120 new cases of invasive breast cancer to be diagnosed in women and 40,920 breast cancer deaths will occur.[1] The four principal

© Red Flower Publication Pvt. Ltd.

modalities of breast cancer management include surgery, chemotherapy, hormonal therapy and radiotherapy. Radiation therapy forms an integral component for treatment of breast carcinoma in both breast conservation and postmastectomy patients to reduce the loco-regional recurrence and mortality rate. Postmastectomy radiotherapy (PMRT) commonly administered using low energy 6 MV photon beams by three dimensional conformal radiotherapy (3D-CRT) offers an improvement in 15 years loco-regional recurrence rate from 29% to 8% in node positive subjects and 5% reduction in mortality rate.[2] Radiotherapy planning with opposed tangential fields and application of immobilization devices such as thermoplastic sheet is used to achieve the required dose on surface along with adequate coverage of dermal lymphatics and postmastectomy scar resulting in an advantage of superior dose coverage to the target volume, while reduced dose to the surrounding tissue including organs at risk (OAR) and avoidance of the contralateral breast. The thermoplastic sheets provide great reproducibility in daily treatment, reduces both intra and inter-fractional variability, minimizes skin folds, reduces the set up time and improves accuracy of tumor localization with the help of markers on the device surface.[3,4] It also has an advantage of giving psychological benefit to the patient as well as can influence PTV. These devices are light weight, easy to set-up, comfortable, strong and durable, accommodative with least storage space, also minimally affect the mega-voltage (MV) treatment beam and generate minimal perturbation of the beam so as not to produce any artifacts in the image acquisitions. These are functional on simulator and compatible with computed tomography (CT), magnetic resonance imaging (MRI) and other imaging modalities of treatment planning system (TPS). Additionally, modification can be made to sheet if the patient experienced with swelling or weight loss during the course of treatment by re-heating in water bath. Thermoplastic sheet itself acts as a bolus to the chest wall surface for treatment planning ensuring homogenous dose distribution and reflecting an effective treatment response with minimal morbidity in patients of carcinoma of breast.

In patients given PMRT, chest wall may be strenuous to treat with radiotherapy due to irregular surface contours, large curvature and near-surface target volumes demanding use of a bolus as a very thin layer of skin is present with a low density lung tissue behind. Bolus having properties equivalent to tissue can be used both for compensating the missing tissue or irregular tissue shape, else for modifying the dose at skin surface during whole treatment or part of the treatment course.[5] In some cases where 100% dose is not attained over surface of chest wall by thermoplastic sheet, application of an additional bolus of adequate thickness when irradiated during radiotherapy optimizes the surface dose to skin and chest wall as the skin makes sufficient and required build up while doing planning with tangential fields.Treating the patient without bolus on chest wall reduces the surface dose which is much smaller than that with bolus leading to a limited dose rate, thus a small thickness of the bolus material will lead to a significant increase in the skin dose as being close to the patient and shifting the depth dose curve towards the patient surface.[6] The skin dose measurement recommendations by ICRU and ICRP are at 0.07 mm depth corresponding to the approximate basal cell layer depth and a depth of 0.1 mm has been used as a reasonable reference depth of the basal cell layer of skin while measurements made at an effective depth greater than basal layer depth overestimates the skin dose.[7,8]

Accurate assessment of the surface and superficial dose is useful for clinical consideration to avoid near-surface recurrence while simultaneously limit the skin toxicity. This study aims to compare and assess the outcomes of the dose to skin over tangential field with and without the use of thermoplastic sheet and thermoplastic sheet with additional bolus during PMRT in patients of carcinoma breast.

### *Aim and Objectives*

To determine the dose to skin over tangential field with and without the use of thermoplastic sheet and thermoplastic sheet with bolus during postmastectomy radiotherapy (PMRT) in patients of carcinoma breast and compare the doses amongst these.

## Materials and Methods

This study was conducted on 20 postmastectomy patients enrolled in the outpatient department of Radiation Oncology from January 2017 to June 2018 and treated by radiotherapy using FIF by 3D-CRT technique.

The selected patients had performance status of KPS score of ≥ 70, postmastectomy patient with histologically proven infiltrating ductal breast carcinoma and no evidence of distant metastasis. The chest wall radiotherapy was given after completion of chemotherapy. Thermolplastic sheet (orfit, Belgium) a plastic cast made of polycaprolactone with a density of approximately 1.13 $g/cm^3$ softened by soaking in warm water for a few minutes in water bath at 60 to 63 degree celsius. As wet, these were moulded by stretching around the chest according to the patient's contour and allowed to harden in the treatment position as it gets conformed to the contour of the treatment area. The thermoplastic sheet built in the mould room was placed over the patient lying in supine position and fixed in place with the help of clamps on the breast board to immobilise the chest region and allow treatment along with application of radio-opaque wire for identification of radiation field borders. Siemens SOMATOM Definition AS Scanner (Siemens Medical Systems, Erlangen, Germany) was utilized for CT simulation of all patients. CT images of 3 mm slice thickness were obtained prior to the application of thermoplastic sheet followed by application of thermoplastic sheet of the thoracic region from the angle of mandible till the lower border of L2 vertebra. These images were transferred to the treatment planning system (TPS) Eclipse vs. 13.7.16 (Varian Medical systems Inc. Palo Alto CA) software for target delineation and radiotherapy planning. Delineation of clinical target volume (CTV) with nodal regions, planning target volume (PTV) and organs at risk (OAR) was made on the CT image of all the patients as per contouring guidelines defined by RTOG (Radiation Therapy Oncology Group) to be more systematic, reproducible and error free. While contouring CTV included ipsilateral chest wall with pectoralis muscle, ribs, mastectomy scar and the draining sites inclusive of all three levels of axilla and supraclavicular region (depending upon the stage of the patient) along with the OAR including ipsilateral lung, contralateral lung, heart, spine, contralateral breast (CLB) and liver. A margin of 5mm was given to PTV from CTV for daily setup errors and 3 mm margins were taken to exclude the skin. A dose of 50 gray (Gy) in 25 fractions (50 Gy/25#) at 2 Gy/# with 5#/week schedule was prescribed to PTV for all the patients undergoing treatment.

Plans of FIF by 3D-CRT technique using 6 MV photon energy were generated for the patients in all the three arms with same location chosen for all the depth dose profiles and compared for the dosimetric parameters (Figs. 1–3) All three arms were planned by the same physicist and approved by the same treating radiation oncologist. After approval, all the plans were exported to Clinac for treatment delivery keeping the doses to OAR within tolerance limits in all the three arms. The treatment was delivered to each patient in the treatment room with a medical linear accelerator (Linac).The student paired *t*-test and probability value (*p*-value) was applied for statistical analysis.

## Observation and Results

The age distributionranged from 51 to 60 years and eleven of 20 patients (55%) from the study population had right sided breast cancer while remaining left sided with seven patients at stage IIIA on presentation. Infiltrating ductal carcinoma was found in fifteen postmastectomy patients on final histopathology report.

### *Chestwall hot spot and PTV coverage*

The mean chestwall hot spot in the plans with thermoplastic sheet, without thermoplastic sheet and thermoplastic sheet with additional bolus were found to be 107.81 (±0.45), 108.49(±0.8) and 108.26 (±0.31) respectively (Fig. 4). Thehot spot in the plans with thermoplastic sheet was significantly lesser ($p$-value < 0.001) as compared to that in the other two plans. The mean PTV coverage in the plans with thermoplastic sheet, without thermoplastic sheet and thermoplastic sheet with additional bolus was 93.41 ± 1.54%, 92.36 ± 1.6% and 94.97 ± 1.56% respectively by 3D-CRT technique (Figure 5–6). The PTV coverage was significantly higher in plans with thermoplastic sheet with additional bolus followed by higher in plans for thermoplastic sheet ($p$-value < 0.001) than in without thermoplastic sheet.

### *Surface depth of 90% and 95% dose*

The 90% and 95% mean depth doses upon comparing the groups with thermoplastic sheet and without thermoplastic sheet on identical points by similar CT images in the plans were found to be 0.11 ± 0.05 cm and 0.19 ± 0.07 cm; 0.17 ± 0.06 cm and 0.27 ± 0.07 cm respectively by 3D-CRT technique (Fig. 7). The depth differences for both 90% and 95% doses in the two plans of with and without thermoplastic sheet was statistically highly significant ($p$-value < 0.001). In all the plans with thermoplastic sheet with additional bolus whole skin in the treatment area was well covered with more than 95% dose.

### *Skin dose at 0.1 cm from skin surface*

We measured the dose in Gy received at 0.1 cm from the skin in the two plans for with thermoplastic sheet and without thermoplastic

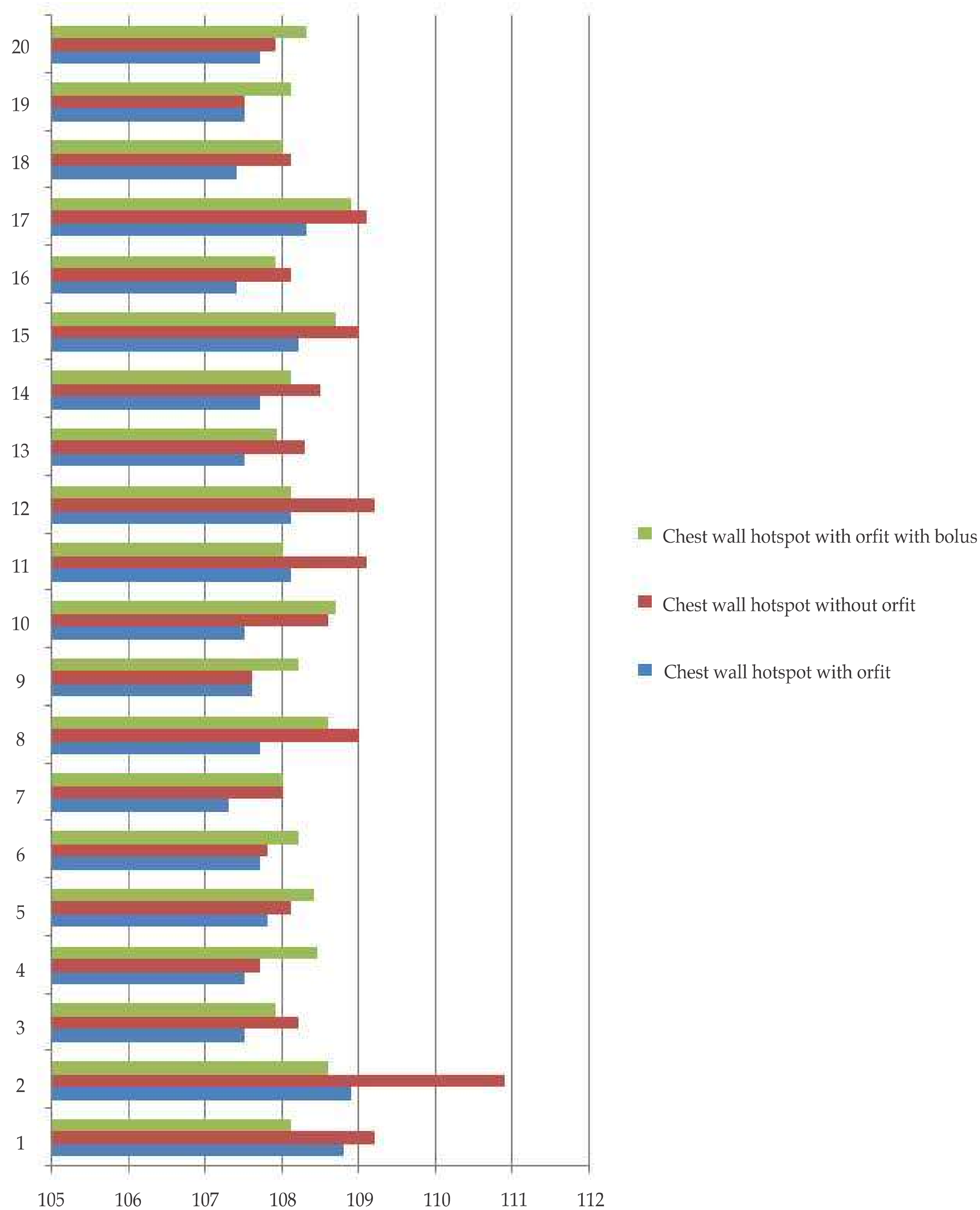



**Fig. 1:** Chest wall hotspot

sheet on identical points. The mean dose in the arm with thermoplastic sheet (91.12 ± 3.09%) was significantly higher than without the thermoplastic sheet (85.83 ± 3.11%) (Fig. 8). This difference was statistically significant in the mean dose at 0.1 cm from the skin surface between the two plans ($p$-value <0.001). In all the plans with thermoplastic sheet with additional bolus whole skin in the treatment area was well covered with 100% dose.

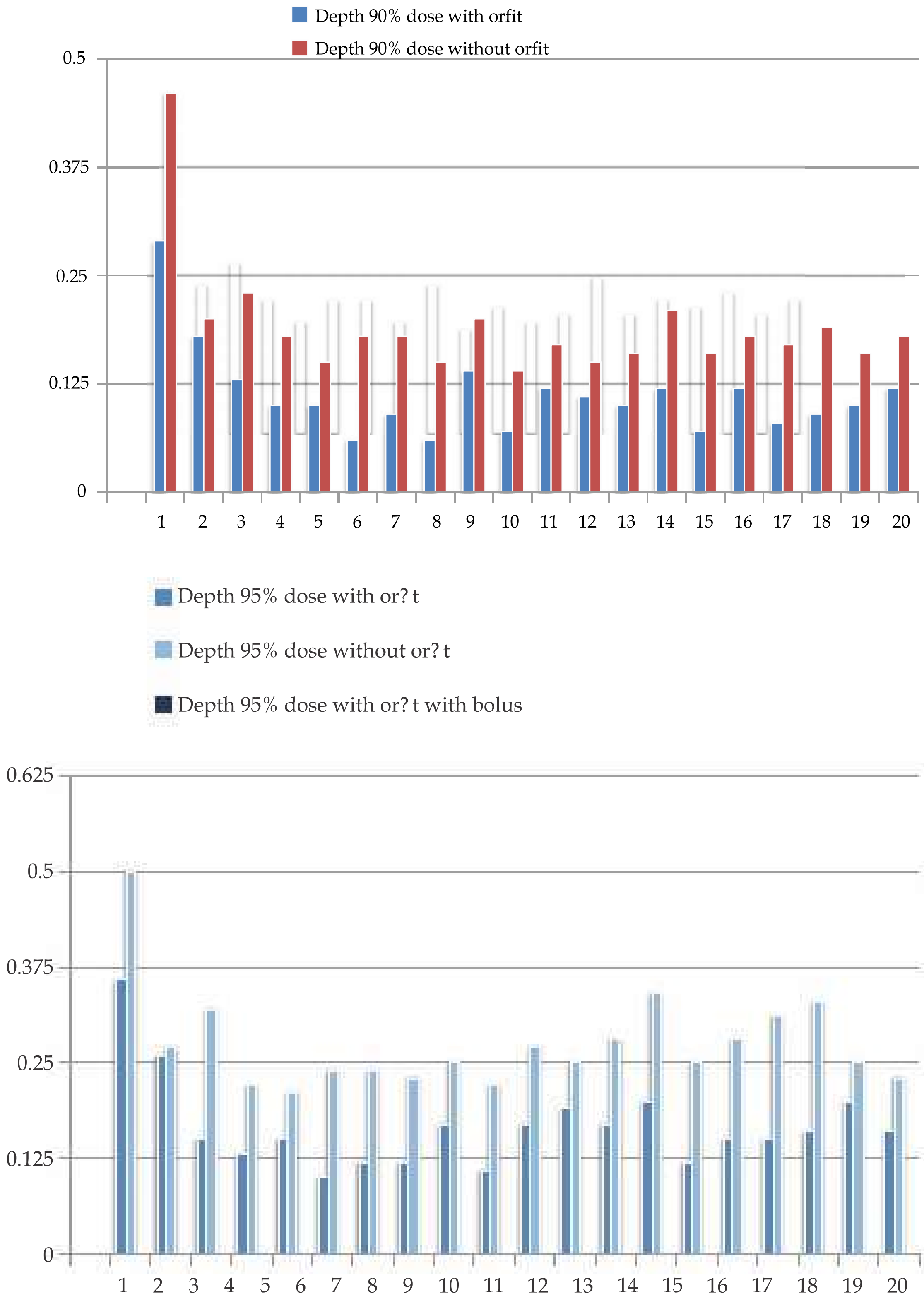



**Fig. 2:** Assessment and comparison of depth isodose distribution from skin (cm) received in all three plans by 3D-CRT technique on identical points

**Fig. 3:**

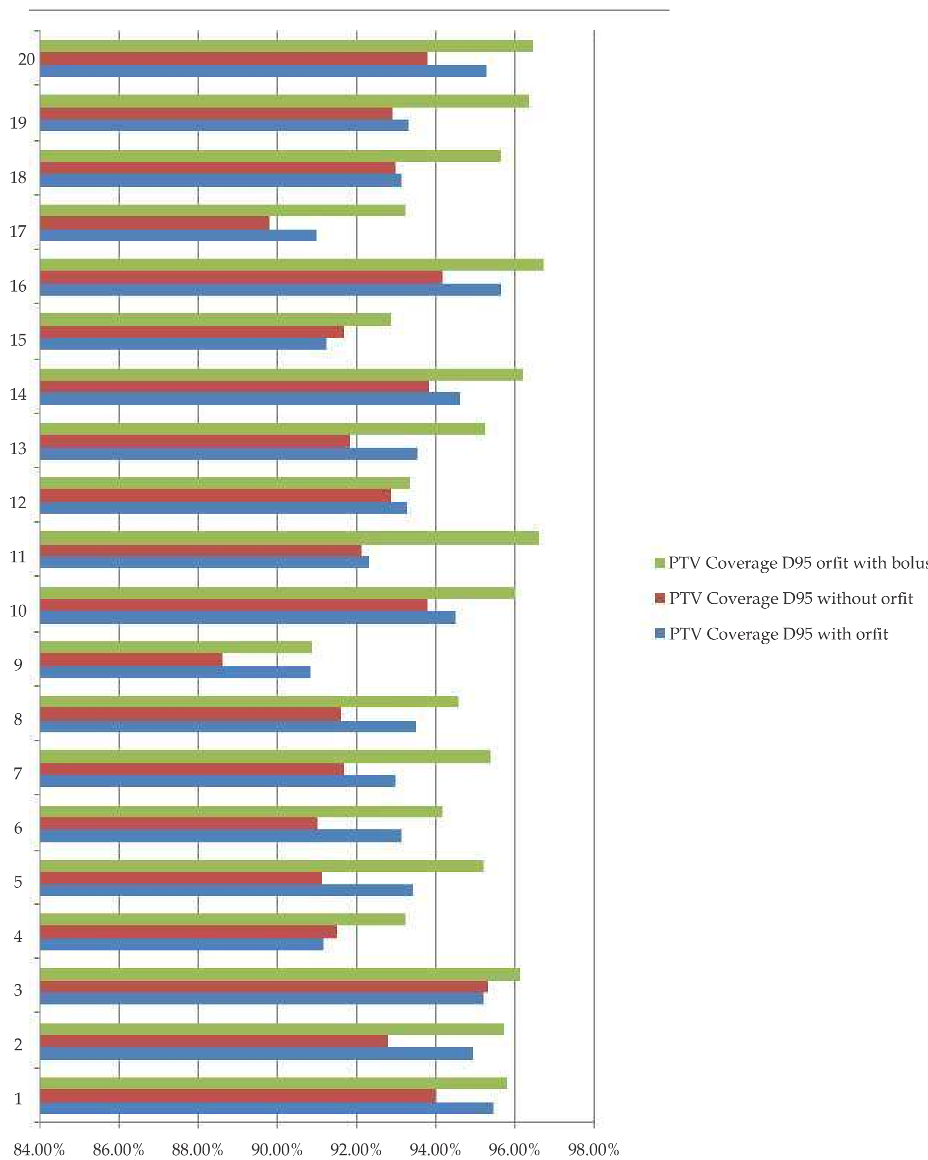
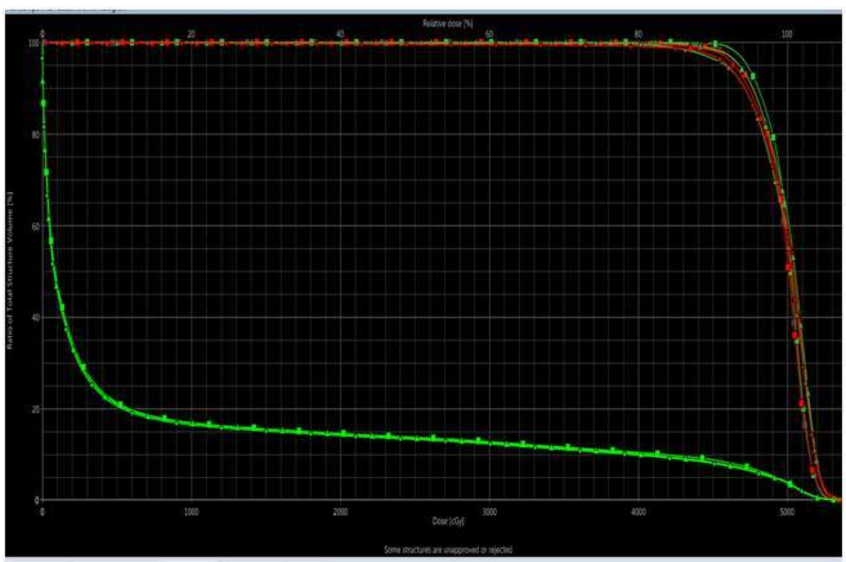



**Fig. 4:** Assessment and comparison of doses received in all three plans by 3D-CRT technique:PTV coverage D95

**Fig. 5:**



Red=PTV; Green= CTV; ■=with orfit ▲=without orfit; ●=with orfit with additional bolus

**Fig. 6:** DVH for PTV coverage in all three plans by 3D-CRT technique for one of the patient

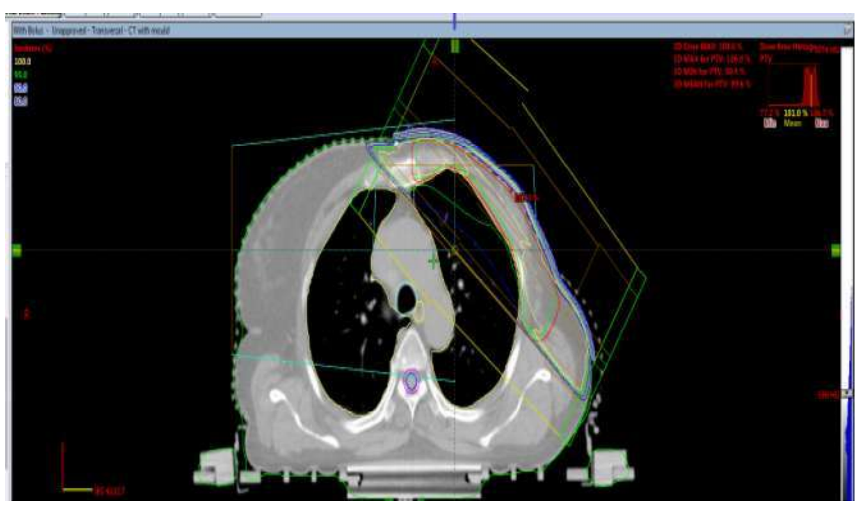


**Fig. 7:**

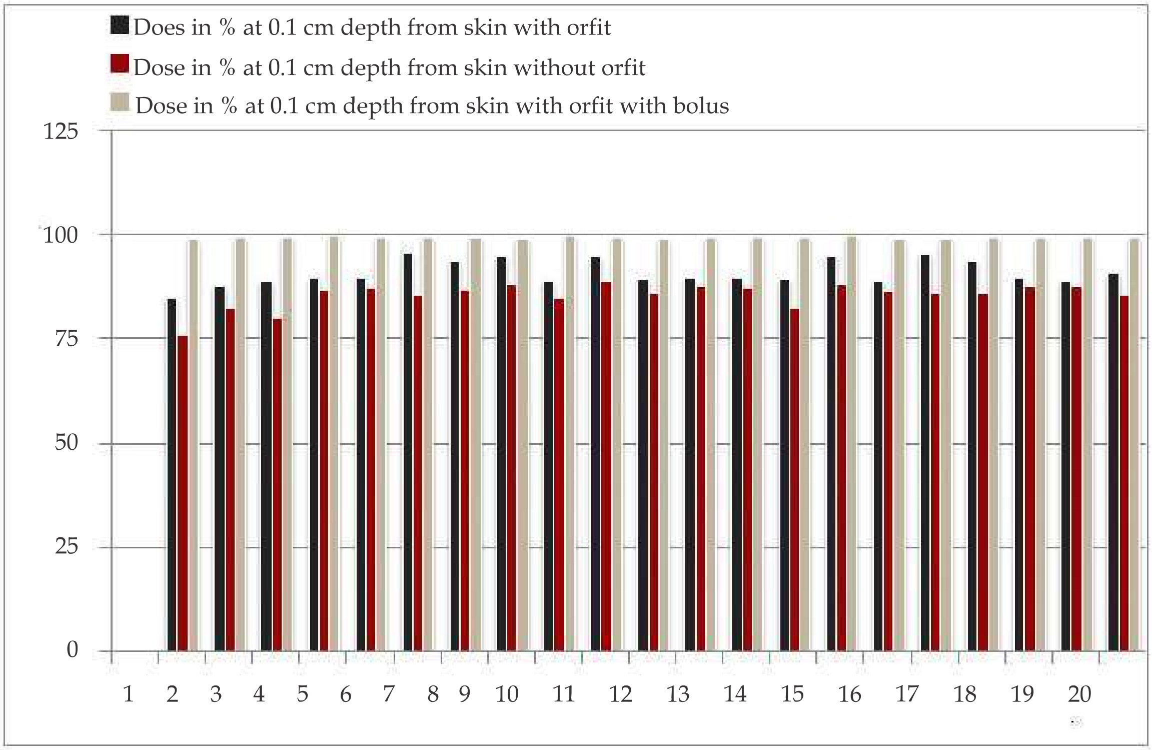



**Fig. 8:** Assessment and comparison of dose at 0.1cm depth from skin received in the plans by 3D-CRT technique on identical points

**Table 1:** .Hounsfield unit) HU (and density measurement of chest wall ,lung and soft tissue

| No. of points in given medium | HU of chest wall | HU of lung | HU of soft tissue |
|---|---|---|---|
| 1 | –71 | –683 | –26 |
| 2 | 38 | –694 | –28 |
| 3 | –120 | –671 | –94 |
| 4 | –122 | –743 | –3 |
| 5 | –100 | –669 | 70 |
| 6 | –115 | –725 | 79 |
| 7 | –30 | –713 | –71 |
| 8 | –101 | –704 | –107 |
| 9 | –113 | –701 | –72 |
| 10 | 53 | –722 | –56 |
| 11 | 46 | –679 | –106 |
| 12 | 10 | –688 | 74 |
| 13 | –47 | –744 | 44 |
| 14 | –64 | –701 | –80 |
| 15 | –90 | –724 | –42 |
| 16 | –73 | –717 | –59 |
| 17 | –88 | –798 | 63 |
| 18 | –40 | –789 | –38 |
| 19 | –78 | –716 | 36 |
| 20 | 44 | –701 | 21 |
| Mean HU | –53.05 | –714.1 | –19.75 |
| Density (g/cc) | 0.94 | 0.28 | 0.98 |

**Table 2:** Hounsfield unit (HU) and density measurement of pine wood and SP34 slabs

| No of points in given medium | HU of pine wood slab | HU of SP34 slab |
|---|---|---|
| 1 | -732 | –36 |
| 2 | –748 | 5 |
| 3 | –730 | 11 |
| 4 | –721 | –18 |
| 5 | –715 | 11 |
| 6 | –740 | –12 |
| 7 | –709 | 13 |
| 8 | –720 | 4 |
| 9 | –749 | –19 |
| 10 | –722 | –17 |
| 11 | –731 | –20 |
| 12 | –733 | 8 |
| 13 | –735 | 13 |
| 14 | –718 | 15 |
| 15 | –721 | 2 |
| 16 | –713 | 15 |
| 17 | –717 | –36 |
| 18 | –719 | –5 |
| 19 | –743 | –6 |
| 20 | –755 | –35 |
| Mean HU | –728.55 | –5.35 |
| Density (g/cc) | 0.27 | 0.99 |

**Table 3:** Isodose depths in CT images of the patient and HTP

| Isodose lines (%) | Isodose depth in patient (cm) | Isodose depth in S-P-S phantom (cm) |
|---|---|---|
| 100 | 1.5 | 1.5 |
| 90 | 4.24 | 4.16 |
| 80 | 7.24 | 7.13 |
| 70 | 11.82 | 10.4 |
| 60 | 16.38 | 14.67 |
| 50 | 19.6 | 19.28 |
| 40 | 23.71 | 23.98 |

**Table 4:** Dose at different depths in CT image of the patient and HTP

| Depth (cm) | Planned dose on TPS (cGy) | Measured dose on LA (cGy) | % variation |
|---|---|---|---|
| 6 cm | 83.8 | 83.4 | –0.47 |
| 10 cm | 73.6 | 74.2 | 0.81 |
| 18 cm | 54.1 | 55.4 | 2.4 |

## Discussion

The use of radiation therapy has reduced the risk of local recurrence and improved the overall survival in breast cancer patients. The skin over chestwall region is at a risk for harbouring potential cancer cells within lymphatics present in a portion of basal cell and dermal layer of skin, which is targeted not on the surface, but 1 to 5 mm below the surface.[9] The skin dose measurement recommendations by ICRU and ICRP are at 0.07 mm depth corresponding to the approximate basal cell layer depth and a depth of 0.1 mm has been used as a reasonable reference depth of the basal cell layer of skin while measurements made at an effective depth greater than basal layer depth overestimates the skin dose.[10,11] As 6 MV photon beams produce a buildup dose effect within first few centimeters of depth with the $D_{max}$ being at a specific depth of 1.5 cm followed by characteristic attenuation with increasing depth of tissue matter. This region is of utmost importance especially in the superficial layer of skin and chest wall area where there is a requirement to keep the near surface dose reasonably high to reduce the risk of scar recurrence in skin in postmastectomy irradiation. The surface dose can be increased by purposeful placement of buildup material on the skin to bring it up to maximum.

Chiu-Tsao and Chan[12] observed a significant 2D bolus effect on skin doses in the presence of patient support and immobilization devices that was confirmed and quantified with EBT film dosimetry. The relative dose (RD) for conventional field was calculated by dividing the dose value by 9.7 Gy for 1000 MU at $D_{max}$ (1.5 cm) on central axis 10 × 10 $cm^2$ field. In the primary 6 MV field, the RD was about 20% for open field (air interface) relative to the central axis dose at $D_{max}$ and at the same effective depth at 0.0153 cm in the film layer average RD was 71% for orfit indicating the highest skin dose for orfit carbon fiber plate. Also, the enhancement factor defined as ratio of minimum dose received in a given area with and without the support device. The enhancement factor was the highest (3.4) for the orfit carbon fiber plate.

Olch *et al.*[13] described in the study of dosimetric effects caused by couch tops and immobilization devices that for thermoplastic devices without stretching, the surface dose increased by 61% compared to 16% without a mask using 6 MV photons.

Mellenberg[14] had earlier shown that use of immobilization devices such as thermoplastic sheets over the patient increases the surface and build-up region dose and degrade the skin sparing expected from high energy photon beams proportional to their thickness and density, the study had shown that a 2 mm thick thermoplastic mask increases the surface dose by 144% (21% absolute) and 99% (12% absolute) for 6 and 15 MV X-rays, respectively.

Andrew Kelly *et al.*[15] conducted a study of the surface dosimetry for breast radiotherapy in the presence of immobilization cast material. The aim of the study was 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 metal oxide semiconductor field effect transistor (MOSFET) detectors at a range of water equivalent depths representative of the different skin layers. The results had shown an increase in skin dose in the presence of the immobilization cast of up to 45.7% and 62.3% of the skin dose than without the immobilization cast 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 and also greater under entrance dose conditions compared to exit dose conditions.

Hadley *et al.*[16] studied the increase in surface dose caused by thermoplastic masks determining that skin sparing effect of 6-MV and 15-MV X-ray beams can be reduced when the patient's skin surface is under the mask material. The surface dose was estimated to change from 16% for 6 MV and 12% for 15 MV, respectively, from 27% without mask and to 61% with mask for 6 MV and from 18% without mask to 40% with the mask samples for 15 MV.

Bilge *et al.*[17] determined the effects of immobilization on build-up and exit dose regions for high energy photon beams measurements in central axis of Co-60 and 4, 6 and 15 MV photons at various field sizes and source to phantom distances were made in a water equivalent solid phantom with 2, 5 and 10 cm thick uniform styrofoam beds at the surface. The surface dose increased almost linearly with field size for Co-60, 4, 6 and 15 MV X-ray beams. The effect of immobilization on the surface dose increased with the thickness and this effect was lower with higher energies. When a 2 cm thick Styrofoam bed was used for immobilization, the surface dose in a 10 × 10 cm field was higher 43.9, 36.8, 28.8 and 14.9% for Co-60, 4, 6 and 15 MV, respectively, with greater thickness, the maximum dose point moved closer to the surface of the phantom for all energies and the exit surface dose was also enhanced similar to the effects on the surface dose. This enhancement was the maximum 5% for high energy photon beams and 6% for Co-60 beam. Thus, use of immobilization device in the radiation beam of the patient increases surface and exit doses to a considerable extent.

Quach *et al.*[18] demonstrated that addition of a 1 cm thick bolus lead to a large increase of approximately 350% in dose at shallow incident angles of 60 degree while at steep incident angles of 140 degree the incident dose increment was only by 10%. This increased entrance dose was a result of increase in buildup material whereas the increased exit dose was due to an increase in back scatter material. Thus, the use of a thicker bolus gives a more homogeneous final dose distribution as bolus is close to the $D_{max}$ thickness where dose gradients are reduced.

## Conclusion

The extensive use of site specific immobilization devices for the purpose of immobilization to ensure accurate daily reproducible position of the patient and day-to-day set-up error reduction during the treatment of carcinoma patients is of utmost importance.

For use with breast radiotherapy there are additional potential advantages. The foremost of these being a shift in breast tissue antero-medially which could lessen the volume of lung and heart tissue within the field. The second advantage is a reduction in skin folds receiving high dose, and the third, a reduction in chest wall motion important to improve dose homogeneity with the primary advantage of providing a bolus effect to the entire chest wall surface.

*Sources of support:* NIL

*Ethical Issues:* NIL

*Conflicting Interest:* NIL

## References

1. Smith R, Andrews K, Brooks D, *et al*. Cancer screening in the United States, 2018: A review of current American Cancer Society guidelines and current issues in cancer screening. 2018.
2. Clarke M, Collins R, Darby S, *et al*. Effects of radiotherapy and of differences in the extent of surgery for early breast cancer on local recurrence and 15-year survival: an overview of the randomised trials. Lancet. 2005;366: 2087–2106.
3. Strydhorst JH, Caudrelier JM, Clark BG, *et al*. Evaluation of a thermoplastic immobilization system for breast and chest wall radiation therapy. Med Dosim. 2011 Spring;36:81–4.
4. Agostinelli S, Garelli S, Bellini A, *et al*. Helical Tomotherapy of the breast: can thermoplastic immobilization improve the reproducibility of the treatment setup and the accuracy of the delivered dose? Phys Med. 2015 Feb;31:49–53.
5. Ordonez-Sanz C, Bowles S, Hirst A, *et al*. A single plan solution to chest wall radiotherapy with bolus? Br J Radiol. 2014;87:20140035.
6. Olch AJ, Gerig L, Li H, *et al*. Dosimetric effects caused by couch tops and immobilization devices: report of AAPM Task Group 176. Med Phys. 2014 Jun;41:061501.
7. ICRU. Recommendations of the International Commission on Radiological Protection. Ann. ICRP. 1991;21:1–201.
8. Carl J and Vestergaard A. Skin damage probabilities using fixation materials in high-energy photon beams. Radiother. Oncol. 2000;55:191–198.
9. Chow JCL, Grigorov GN. Surface dosimetry for oblique tangential photon beams: a Monte Carlo simulation study. Med Phys. 2008;35:70–76.
10. ICRU. Recommendations of the International Commission on Radiological Protection. Ann. ICRP. 1991;21:1–201.
11. Carl J and Vestergaard A. Skin damage probabilities using fixation materials in high-energy photon beams. Radiother. Oncol. 2000;55:191–198.
12. Chiu-Tsao ST and Chan MF. Evaluation of two-dimensional bolus effect of immobilization/ support devices on skin doses: a radiochromic EBT film dosimetry study in phantom Med. Phys. 2010;37:3611–20.
13. Olch AJ, Gerig L, Li H, *et al*. Dosimetric effects caused by couch tops and immobilization devices: report of AAPM Task Group 176. Med Phys. 2014 Jun;41:061501.
14. Mellenberg D. Dose behind various immobilization and beam-modifying devices. Int. J. Radiation Oncology Biol. Phys. 1995;32:1193–7.
15. Kelly A, Hardcastle N, Metcalfe P, *et al*. Surface dosimetry for breast radiotherapy in the presence of immobilization cast material. Physics in Medicine and Biology. 2011;56:1001–13.
16. Hadley SW, Kelly R, Lam K. Effects of immobilization mask material on surface dose. J ApplClin Med Phys. 2005 Winter;6:1–7.
17. Bilge H, Yondem S, Kucucuk H, *et al*. Effects of immobilization beds on the dose in the entrance and exit dose region for Co-60, 4, 6 and 15 MV photons. J BUON. 2008 Jul-Sep;13:385–90.
18. Quach, KY, Morales, J, Butson, *et al*. Measurement of radiotherapy x-ray skin dose on a chest wall phantom, Medical Phys. 2000 Jul;27:1676–80.