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An Evaluation of Methods to Reduce Inframammary Surface Dose in Prone Breast Irradiation

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Abstract

In cases of breast radiation treatments via external beam radiation therapy, the incidence of radiation dermatitis has been reported. In prior studies, this acute radiation side-effect has been correlated with the immobilization devices in cases of prone breast irradiation. They attribute this to the bolus effect that occurs with the interaction of the incident photon beam at different projections causing an increase in measured surface dose. The type of radiation planning technique, and patient positioning during the undertaking of these techniques, have also shown to influence this bolus effect. This study focuses on these factors in treatment planning in order to reduce the issue of bolus effect in the inframammary fold. Standard 3D conformal, a non-coplanar, and IMRT techniques are employed to evaluate effectiveness in counteracting the inherent bolus effect. The resulting data recorded via MOSFET dosimeters failed to show a significant difference between standard 3D technique and non-coplanar technique. However, IMRT/VMAT technique showed significant differences between the 3D planning techniques, even with the alteration of patient positioning. These results show promise in utilizing IMRT planning techniques as a pre-emptive practice for reducing the chance of acute skin dermatitis in prone breast radiation therapy. Future studies should consider these findings, along with the discussed limitations, to examine potential improvements in research methods in evaluating increased surface dose during breast radiation therapy.

Keywords: prone breast, radiation therapy, bolus effect, increased surface dose, non-coplanar technique

I. TITLE:

An Evaluation of Methods to Reduce Surface Dose in Prone Breast Irradiation

II. INTRODUCTION AND BACKGROUND

Breast cancer is the most diagnosed cancer in the world with a reported number of 2.3 million newly diagnosed cases in 2020 [1]. Current techniques in the treatment of breast cancer continue to evolve and the intent is always geared towards investigating approaches that are effective while minimizing toxicities. Treatment using radiation is one area that has benefited from these efforts in the past decade. For example, radiation oncologists have widely utilized a deep inspiratory breath hold technique that has resulted in less cardiac dose to the patient [2]. Additionally, new changes in treatment regimens, such as hypofractionation, have shown promising outcomes in further reducing normal tissue complications [3]. Applying methods such as these in adjuvant radiation therapy techniques following partial breast mastectomy procedures have shown a reduction in side effects, an improved quality of life, and an increased chance of survival [1-5]. Despite these improvements in treatment, there remains the issue of skin reactions associated with breast cancer treatments.

It is not uncommon for patients undergoing breast cancer treatment to experience some degree of radiation dermatitis [3-4]. This specific side effect has been correlated with late occurring complications such as telangiectasis and fibrosis [4]. These long-term consequences are a concern for patients who are expected to have increased chances of long-term survival after the treatment of breast cancer. Therefore, methods in reducing skin dose are imperative. In some cases, the solution can be found in prone breast irradiation. The alteration to the patient's positioning from the traditional supine position to the prone position is employed to reduce

normal tissue toxicities [4,6,7]. Of these toxicities, skin irritation caused by radiation, or simply radiation dermatitis, is a main reason for choosing to treat in the prone position. The common patient indicator for prone positioning is large or pendulous breasts, but the method can be used for any cases of early-staged breast cancer with negative nodal involvement [5]. Despite the benefits of this method, incidence of radiation dermatitis has been reported in clinical studies involving prone breast irradiation [5-6]. Researchers in these cases attribute this persistent toxicity to the involved attenuation occurring within the incidental components of the prone positioning device. It is apparent that the prone breast board, and where the patient is positioned on the device, can inadvertently cause a bolus effect, subsequently increasing surface dose [5]. This increase of dose to the surface during prone breast irradiation will be the issue of focus in this study.

i. AIMS

This research aims to evaluate methods in reducing bolus effect associated with the use of prone breast boards during breast radiotherapy. We will assess the use of 1) an altered beam arrangement, 2) IMRT, Intensity Modulated Radiation Therapy, 3) varying positioning on the featured immobilization device, all with patients in the prone position.

ii. LITERATURE REVIEWS

Although innovative, the alternative prone positioning method does not resolve the issue of dry/moist desquamation completely in breast irradiation. The problem may prompt investigation in the possible causes of this persistent skin reaction. A prime example of this is seen in a study conducted in Japan [6] that involved a prospective study on implementing the prone position in cases with larger breast volumes. A finding in their research is of an unexpected increase in radiation induced dermatitis. Takahashi et al., attributed this occurrence

to a bolus effect caused by the positioning device used in these treatment setups. The use of surface dose measuring equipment was a unique strategy portrayed in the study and could prove valuable in evaluating skin dose in further research involving pone breast irradiation; this relieves total dependence on the TPS, Treatment Planning System, in accurately calculating dose to the patient's skin. Rational for avoiding dependence on the TPS involves several factors, including limitations of the planning software, such as grid ratios [5]. Accurate dose representations are imperative in studying dosimetry impacts caused by external factors, such as in the study of Takahashi et al.

The incidental finding of bolus effect is not an isolated occurrence. A recent study by Lau et al. [5], concurs with the proposed bolus effect caused by prone breast boards. In their discussion, they stress the importance of properly accounting for external structures, as they can cause a reduction in target coverage and lead to an increase in dose. The bolus effect was an important factor observed in these changes. Their data showed a 65-93% increase in surface dose when the prone breast device was introduced, compared to when it was not involved [5]. Lau et al., went on to establish a key relationship between patient positioning and the intensity of bolus effect; the closer the breast was to the insert of the prone breast board, the more pronounced the change in surface dose. This finding is significant in the case of prone breast irradiation, considering variability of the patient's positioning during daily setups. These setup variations then correlate to a possible shift in separation of the breast from the breast board insert, resulting in a dosimetric impact. In the study, a reduction in the separation translated to an increase in involvement of the positioning device in the treatment field. In addition to this positioning factor, Lau et al proposed that a change in gantry angle may have an influence on the observed effect of attenuating external structures [5]. The beam projection onto the prone board insert component

showed a measured difference in surface dose. This is comparable to the effect regarding the angle of incidence on bolus material using photon radiation [8]. This outcome is worth investigating for the purpose of finding an optimal beam entrance projection in the treatment of breast cancer in the prone position.

Additional articles provide more information in reducing the incidence of radiation dermatitis. Some focus on the implementation of nonconventional treatment techniques (techniques other than simple 3D tangential techniques) coupled with the prone position. One such study by Gopalakrishnan et al. [9] found that IMRT delivered the least amount of surface dose to the treated breast in comparison to a variety of other treatment techniques. In the study, Gopalakrishnan et al. employed a wax phantom and the use of OSLDs, optically stimulated luminescent dosimeters, dispersed across the make-shift breast volume. Results showed a more evenly spread-out surface dose, compared to other treatment techniques. This homogenous dose distribution is a key component when considering potential skin doses. A treatment technique that allows for more homogeneity may deliver less dose at the surface [9,10]. Gopalakrishnan et al. found that IMRT delivered up to 50% less surface dose. They attributed this significant reduction to the ability of dose modulation, even in the presence of irregular surfaces. Regarding the issue that is radiation dermatitis, this in-depth investigation on the effects of IMRT on surface dose is substantial. The results proceed rational for implementing a new standard in prone breast planning techniques.

The proposed bolus effect remains an issue that requires investigative efforts in the research community. Studies have already established the presence of the effect involved with prone positioning setups and have attempted to quantify the potential dosimetric consequences [5,6,9]. Rather than simply identifying the issue and measuring the resulting surface doses, this study

will focus on evaluating a selection of methods in reducing the negative impact of increased surface dose caused by the bolus effect.

III. MATERIALS AND METHODS

Equipment

This work investigated methods to reduce the inadvertent bolus effect observed with the positioning device used for prone breast irradiation. There was focus on evaluating the surface dose produced by using a set of proposed techniques based on prior research discussions: an altered beam projection, IMRT treatment technique, and varying positioning. A breast phantom, which is comprised of a RANDO thorax and silicone breast prostheses, was designated for use in this study. The RANDO thorax component was fabricated specifically for the mapping of dose distribution that is essential for evaluating treatment planning in radiotherapy. It has a 23 cm anterior-posterior thickness and 33 cm width. This phantom was chosen because it simulates an average adult torso and can be positioned in the prone position with ease, which is ideal for repositioning during the treatment delivery process. The phantom includes pertinent structures such as lungs, spine, and surrounding bony anatomy. These fabricated internal structures simulate the tissue densities of the actual human thorax. The silicone breast protheses is composed of material with a density equivalent to that of adipose tissue. The volume of the breast phantom mimics the size and dimensions of the female breast.

The RT-6025 prone breast board (Bionix Radiation Therapy, Toledo, OH) was utilized for positioning of the breast phantom. The device is composed of an elevated platform with a hollow support structure (Fig. 1A). The carbon fiber platform surface features foam padding for comfort. A “bridge insert” at the level of the breasts is a removable section, also consisting of foam-padded carbon fiber. The padding measures 2.5 cm in thickness, and the carbon fiber 0.8 cm.

The opening of the insert for the targeted breast is 20 cm wide and 25 cm long. Figure 1B shows the irregular semielliptical shape of the insert opening (Fig. 1B). The insert, along with movable handlebars, aid in reproducing the position of the breast tissue, and indices mounted on either side of the prone breast board ensure proper placement of the patient on the structure.

Fig. 1. *Bionix prone breast board. (A) Full view of breast board showing elevated platform, and (B) Inferior aspect of removable board insert.*

For in vitro dosimetry, a portable MOSFET was utilized, Metal Oxide Semiconductor Field Effect Transistor, (Team Best; Nashville, Tennessee) system with two MOSFETs (TN – 502RD-H, SN: 33545 & 33546). Within these MOSFETs is a small epoxy structure housing a sensitive volume component of 1 mm^2 and an active area of 0.2 mm × 0.2 mm. The electrometer TN RD 70W dose verification system was of standard sensitivity and provided ± 1 Mv dose linearity.

Simulation

A GE, General Electric, 14 slice BrightSpeed scanner (GE Healthcare LLC, Chicago, IL) was utilized to carry out the CT simulation process and to obtain the required cross-sectional images. The steps taken for this procedure mirrored that of general radiation therapy procedures. For the prone breast simulation, the phantom was placed in the ideal treatment position: centered on the Bionix prone breast board, absent of pitch, roll, and rotation. The insert of the prone board

was arranged to simulate a right sided breast treatment (Fig. 2A). Care was taken to ensure adequate centering of the breast prosthesis within the opening of the prone breast board insert. For this study, a separation of 3cm from the breast's medial and inferior surface to the carbon fiber insert was measured (Fig. 2B). After achieving the desired positioning, the body of the phantom was marked at 3 points. The breast board index reading at the location of the marked 3-point was recorded for later use during repositioning at the time of the treatment process. Standard field borders were marked and wired for treatment planning purposes: 1.5cm inferior/lateral/medial in respect to the mammary fold and 1.5cm inferior to the level of the clavicular head. To further increase positional accuracy, the surface of thoracic phantom was marked in relation to the borders of the opening. Photos were taken of the overall setup for reference and the GE scanner was used to obtain cross-sectional images of the entire phantom's length for planning.

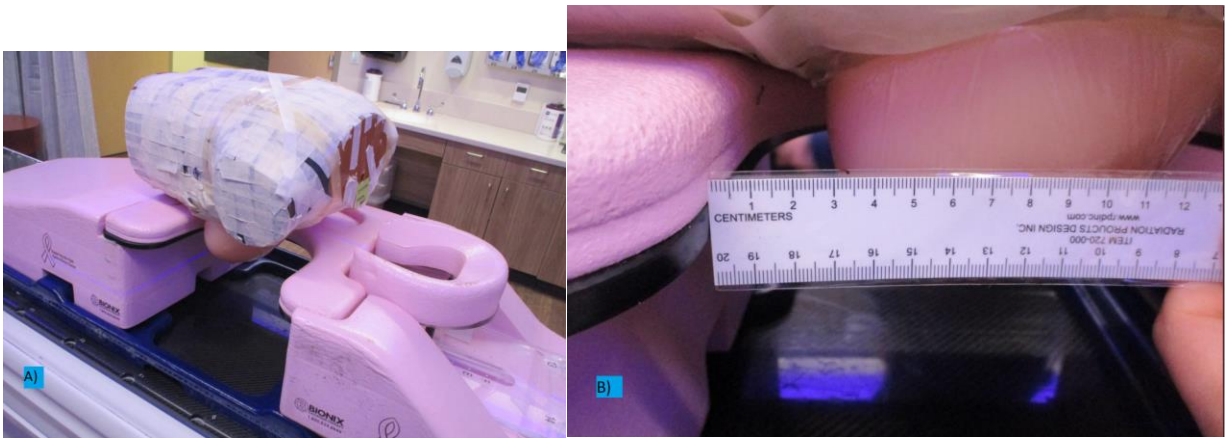


Fig. 2. *(A) Breast phantom positioned atop the Bionix breast board, simulating a right-sided breast treatment, and (B) 3cm separation of the most inferior part of the prosthetic breast and perimeter of insert opening*.

Treatment Planning

DICOM CT images were sent to the Raystation TPS, treatment planning system, version 10A. The planning process was undertaken by qualified medical dosimetrists. All resulting plans were evaluated by a certified medical dosimetrist to ensure they met departmental protocols. The prescription was constant across all plans: 16 fractions of 266 cGy each, for a total of 4256 cGy. The target volume included the breast alone, absent of simulated nodal involvement. The major critical structures used in standard treatments planning (heart, lungs, spinal cord, and contralateral breast) were contoured and reviewed.

The chosen 3D approach included a pair of static beams using a medial and lateral projection. These beams incorporated blocking to omit the heart and lungs. A FiF, field-in-field, technique was used to deliver the most uniform dose distribution possible with a max hotspot below 105% throughout the treatment volume. The dose was prescribed to a point located mid-transverse the treatment volume and 1.5cm away from the phantom's lung volume. This standard 3D plan met completion when 100 percent of the dose covered 95% of the breast per department protocol.

The beam arrangement was altered for a second planning technique. This somewhat novelistic approach was inspired by the findings of Lau et al., with a conclusion consisting of a significant difference in surface dose with respect to beam projection. This led to the featured non-coplanar technique, in which investigates a diverse beam arrangement. The planning for this approach was similar to a standard 3D technique, with the exception of an added projection (medial). The two medial projections were separated by an angle of 16 degrees. The couch must be rotated 8 degrees away from the linear accelerator head and rotated 8 degrees towards it during the treatment. The plan, therefore, entailed a non-coplanar approach, resulting in a spread-

out entrance surface area. This allowed for a decrease in potential dose build up at any one area incident along the beam's path. All the same treatment planning parameters were carried out with this approach as with the standard 3D approach.

The last proposed approach consisted of the IMRT planning technique. For this study, a specific type of IMRT, VMAT, Volumetric Arc Therapy, was used. Following standard treatment planning practices, the dose was prescribed to a volume, opposed to a point (as done in routine 3D planning). Contouring of treatment volumes mirrored that of those in routine practice. Objectives were used within the optimization capabilities of the TPS to achieve 95% coverage of the target volume with 100% of the prescribed dose. Normal tissue constraints also followed that of standard practice: heart mean≤ 250 cGy, ipsilateral lung V20<15%/V5<65%, contralateral lung V20/30%, V5<35%, and contralateral breast V2<1%.

All three approaches were planned for treatment using a Varian Truebeam Linear accelerator Version 2.7 (Varian Medical Systems, Palo Alto, CA) equipped with a Varian couch (6 degrees of freedom and a mass density of .700 g/cm3). The treatment plans applied 6 MV photons and 600 cGy/min dose rate. The Truebeam onboard imaging consisted of a KV, kilovoltage, system that allow for CBCT, cone beam cross-section tomography acquisition. The Prone breast board was first placed atop the couch. The phantom was positioned carefully over the breast board with attention to the marked 3-point and corresponding indexing using the side markers. Verification of accurate repositioning was achieved through the visualization of the marks on the patient obtained during simulation and the borders of the open field. A measurement from the breast to the insert borders was taken to ensure proper separation. After proper manual positioning, the linear accelerator operator performed a CBCT scan for image registration and corresponding couch adjustments.

Once setup accuracy was validated via cross-sectional imaging, MOSFET devices were placed in position. The chosen location for dose measurement was specifically placed in the region of most reported desquamation during prone breast irradiation: the inframammary fold. The portable dosimetry system was set to record in-vitro measurements during the treatment delivery of the standard 3D conformal plan. The dose was recorded and the treatment delivery process was repeated for the two other treatment plans: the non-coplanar plan and the VMAT plan.

For these 3 treatment plans, an initial breast-insert separation of 3 cm was used (the distance of the surface of the breast to the adjacent borders of the breast board insert). This positioning was as planned for during the simulation process. As discussed in the findings of Lau et al. [5], an inverse relationship can be predicted between distance/separation of bolus material to the surface and intensity of the increased superficial dose (bolus effect). To account for a possible limitation in the observed incidence of bolus effect in this study, an alteration in phantom positioning was employed. Each treatment plan was repeated with solely a change in breast-to-insert separation. The plans were carried out with 13 points of breast-insert separations ranging from 0 to 6 cm. The additional readings were then recorded.

Data Analysis

One-way repeated measures ANOVA was used for statistical analysis of the comparison between the recorded surface dose using different treatment planning techniques. Normality of distribution with was tested with SPSS (SPSS Inc. Chicago, IL) statistical software version 24.0. The data were considered statistically significant with $p < 0.0167$.

IV. RESULTS

The goal of this study is to evaluate techniques in reducing the bolus effect involved in prone breast irradiation. By assessing the surface doses recorded after each proposed technique, a significant difference in effectiveness between plan types can be determined. Also, by varying the air gap between the breast and the immobilization device, the influence of patient positioning on surface dose can be evaluated. The planning techniques included in this investigation are 3D conformal, non-coplanar, and IMRT. Repeating the treatment plans for 13 sample points provides the statistical power required for analysis. The employed air gaps ranged from 0 to 6cm in length.

Acquired Data

Since this study employed the use of a phantom for obtaining raw data, patient data was not required. The introduction of varying separation as a covariant allowed for a sample of repeated tests: 13 points at 0.5 cm intervals were acquired during the undertaking of each of the 3 plans. The MOSFET readouts for 39 total data points were recorded in table 1.

Separation (cm)	Standard 3D Conformal	Non-coplanar	VMAT
6	232.8	235.7	194.71
5.5	245.79	241.2	183.48
5	258.54	254.13	168.52
4.5	270.02	260.62	164.61
4	273	265.24	187.3
3.5	273	269.54	179.01
3	275.75	278.35	215.62
2.5	278.88	273.68	187.24
2	283.93	289.36	251.98
1.5	294.7	288.75	204.62
1	281.94	289.4	188.91
0.5	298.6	292.89	240.1
0	310.09	299.53	280.76

Table 1. *Recorded dose (cGy) per plan technique at each separation point (cm).*

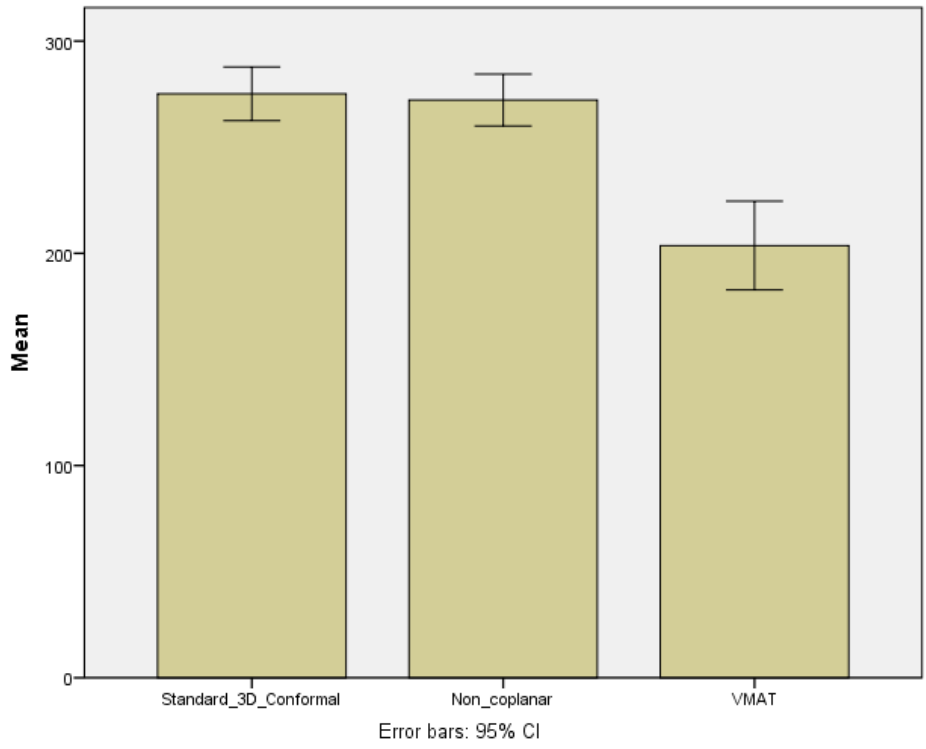
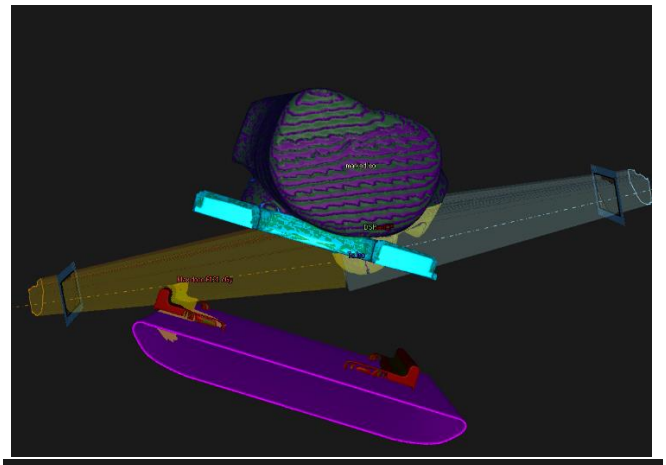


Fig. 3. ***E****rror bar chart shows the 95% confidence interval. The mean surface dose per plan is illustrated.*

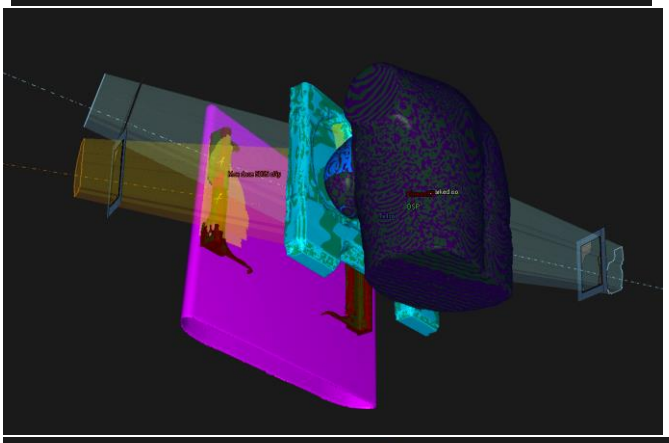
Plan specifications

For the standard 3D conformal plan, 2 beam angles were utilized: 245 degrees (the medial projection) and 60 degrees (the lateral projection). These specific angles resulted in assurance of adequate coverage of the simulated breast volume. This arrangement is seen in figure 4a. The mean dose of the standard 3D conformal plan was 275.16 cGy, with a standard deviation of 20.93 cGy. The recorded values ranged from 232.8 cGy to 310.09 cGy. A bar chart for comparison of this mean dose with the other plans are shown in figure 3.

(a)



(b)



(c)

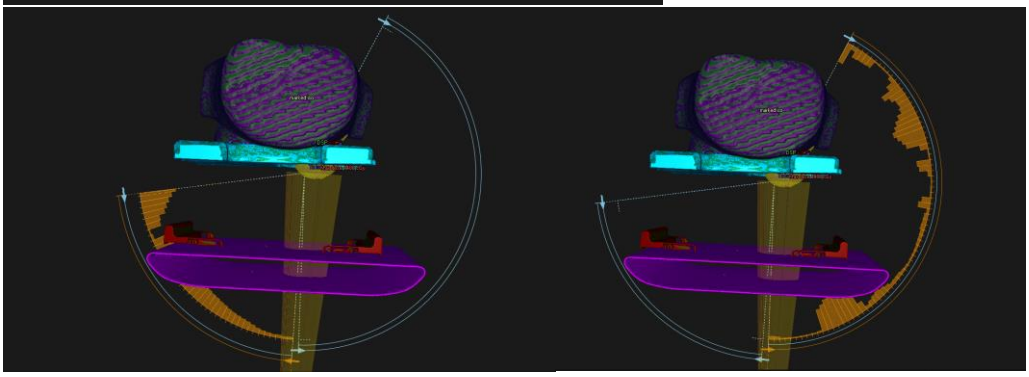


Fig. 4. *3D representations of the external contour of the breast phantom with immobilization device in blue.*

The resultant beam angles for the non-coplanar plan also consist of 245 degrees and 60 degrees, as illustrated in figure 4b. It includes 2 medial beams with separated couch angles: 8 degree and 352 degree couch rotations. The mean dose of the non-coplanar technique was 275.18 cGy with a standard deviation of 20.18. The recorded values ranged from 235.7 to 299.53 cGy.

The VMAT plan included two arcs traveling down the patient's right (25 to 179 degrees, in both a clockwise and contour clockwise direction). Two additional arcs traveled down the patient's left (260 to 181 degrees, also in a clockwise and contour clockwise direction). The traveled angles are shown in figure 4c. The mean dose of the VMAT technique was 203.60 cGy with a standard deviation of 34.59 cGy. The recorded values for this plan ranged from 194.71 cGy to 280.76 cGy.

The "ROI algebra" function in Raystation allowed for the creation of the optimization structure, "PTVopti". This targeted structure is a rendering of the PTV, planning target volume, cropped 0.3 mm from the phantom's surface per general facility protocols. For the most optimal VMAT plan, the highest optimization priority was placed on this optimization structure while smaller priority was given to surrounding critical structure volumes (heart and lungs). In an effort to reduce the volume exposed to lower doses, the external contour of the phantom was employed for optimization. A "ring cooler" structure aided in further reducing low dose coverage and increasing conformity. Figure 5 displays all the optimization objectives and corresponding weighting factors used to create the VMAT plan. The plan was auto-scaled to meet facility standards: 95% coverage of the PTV with 100% of the prescription dose. Before the plan was finalized, the total MU, monitor units, were adjusted to mirror that of the standard 3D conformal and non-coplanar plans.

Physical composite objective				
Min DVH	Plan	PTVopti	Min DVH 4256 cGy to 99% volume	1200.00
Uniform dose	Plan	PTVopti	Uniform dose 4256 cGy	1500.00
Max dose	Plan	PTVopti	Max dose 4460 cGy	1500.00
Dose fall-off	Plan	External	Dose fall-off [H]4256 cGy [L]4043 cGy, Low dose distance 1.00 cm	10.00
Dose fall-off	Plan	External	Dose fall-off [H]4043 cGy [L]2100 cGy, Low dose distance 1.40 cm	50.00
Max EUD	Plan	Heart	Max EUD 250 cGy, Parameter A 1	20.00
Max EUD	Plan	Lung_R	Max EUD 690 cGy, Parameter A 1	1.00
Min DVH	Plan	Breast_R	Min DVH 4050 cGy to 95.5% volume	70.00
Max dose	Plan	RC	Max dose 2128 cGy	1.00

Fig. 5. *Resultant optimization settings for the VMAT plan in Raystation10a*

Variations between Techniques

Descriptive statistics showed the mean for the standard 3D conformal points as the highest with a value of 275.16 cGy to the breast phantom's surface. The lowest value of 203.60 cGy was recorded using the VMAT plan. The recorded mean of the non-conformal plan, 272.18 cGy, was very similar to that of the standard 3D plan.

Mauchly's test indicates that the assumption of sphericity had been violated, χ^2 (2)= 21.952, p <.001. The accepted hypothesis was that the variances of the differences between plans are significantly different. The degrees of freedom are corrected using Greenhous-Geisser estimates of sphericity (€=.54). The results show that there is a significant effect of chosen plan on the surface dose delivered, F(1.073, 12.875) = 93.196, p <.001.

Pairwise Comparisons

Measure: MEASURE_1

(I) Plan	(J) Plan	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	**1.057**	**1.266**	**1.000**	**-2.514**	**4.627**
	3	**37.512***	**10.033**	**.010**	**9.219**	**65.805**
2	1	**-1.057**	**1.266**	**1.000**	**-4.627**	**2.514**
	3	**36.455***	**9.684**	**.009**	**9.146**	**63.764**
3	1	**-37.512***	**10.033**	**.010**	**-65.805**	**-9.219**
	2	**-36.455***	**9.684**	**.009**	**-63.764**	**-9.146**

Table 2. *pairwise comparisons between plans. 1 = standard 3D conformal, 2 = non-coplanr, 3 = VMAT.*

The reported Greenhouse-Geisser p value proved to be significant, which suggests the plan type has a significant effect on surface dose. These results prompt a closer look at the estimated

means of each plan using post-hoc analysis. The mean difference between surface dose of the standard 3D conformal plan and the non-coplanar plan was 1.057 cGy. Standard 3D conformal and non-coplanar plans had a mean difference of 37.512 cGy and 36.455 cGy, respectively, compared to the VMAT plan. Table 2 illustrates the comparisons of mean surface dose recorded between each of the 3 plan types.

Variations of surface dose involving varying separations

Additional ANOVA testing was done to assess variance accounting for separation. This addition of a covariant was necessary to determine if separation had a significant effect on the surface dose delivered. This resulted in SPSS analysis of mean dose directly related to mean centigray per centimeter (cGy/cm).

Pairwise Comparisons

Measure: MEASURE_1

(I) Plan	(J) Plan	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	**2.973**	**1.587**	**.257**	**-1.439**	**7.385**
	3	**71.552***	**7.275**	**.000**	**51.332**	**91.773**
2	1	**-2.973**	**1.587**	**.257**	**-7.385**	**1.439**
	3	**68.579***	**7.075**	**.000**	**48.915**	**88.243**
3	1	**-71.552***	**7.275**	**.000**	**-91.773**	**-51.332**
	2	**-68.579***	**7.075**	**.000**	**-88.243**	**-48.915**

Table 3. *pairwise comparisons of mean surface dose with focus on seperation meausrements between planning techniques. 1 = standard 3D conformal, 2 = non-coplanr, 3 = VMAT.*

The specified Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (2)= 21.952, p = <.001. Once again, we accept the hypothesis that the variances of the differences between plans are significantly different. The degrees of freedom are corrected using Greenhous-Geisser estimates of sphericity (Є=.54). The results show that there is a significant effect of the chosen plan on the surface dose delivered at each separation point, F(1.073, 12.875) = 93.196, p <.001. The mean difference between surface dose of the standard 3D conformal plan and the non-coplanar plan was 2.973 cGy, as shown in table 3. Standard 3D conformal and non-coplanar plans had a mean difference of 71.552 cGy and 68.579 cGy, respectively, compared to the VMAT plan.

V. DISCUSSION

The possibility of reducing the bolus effect in the presence of a prone breast board device directed efforts in this study. Analysing the data acquired during the application of 3 different planning techniques allowed for the determination of possible solutions. Regardless of the degree of influence of each plan, the objective of this research is to guide further research in this area of study by providing a base approach to the issue. Current research establishes the existence of an increased dose during prone breast radiation therapy techniques and these studies have also correlated the effect to the prone breast board used as an immobilization device. However, no research has explored methods directly employed to reduce the bolus effect in these situations. This work investigated approaches that differ from the standard 3D approach: a non-conformal and a VMAT technique. Therefore, the standard 3D plan served as a base technique regarding the other discussed plans. A variation in seperation was employed, which addressed the influence of the distance between the breast surface and incident device component in the bolus effect interface. This is representative of the air gaps present in the bolus effect.

The obtained results determined that a concise answer may not lay with the alteration of beam projection. The mean dose recorded during the application of the non-coplanar plan, in which explored an alteration in beam entrance locations, did not significantly differ from that of the standard 3D plan. A glance at the descriptive statistics shows a single centigray difference in mean dose. The attempt to change the beam projection to increase the surface area of beam incidence proved to have no significant effect on the apparent bolus effect. This remains true even with consideration of the separation present in the bolus effect.

In comparison to the standard 3D planning, VMAT showed a significant difference in mean dose. The factoring of separation in mean dosage was also significantly different. This is consistent when comparing to non-coplanar planning. Fig. 6 illustrates the variance in dose distribution at each separation point. Both the significant difference in mean dose and distribution of data points, may be attributed to factors that are special to VMAT treatment techniques. The modulation of the incident beam involved in VMAT technique can pose unique interactions upon the incident immobilization device components. These possible factors go beyond the aspects of this study, but as seen in prior studies, this could involve the homogeneous dose distribution involved in the presence of irregular surfaces [9,10]. The inclusion of VMAT should serve as a basis for comparison of contemporary treatment planning for prone breast planning and other available techniques in the field.

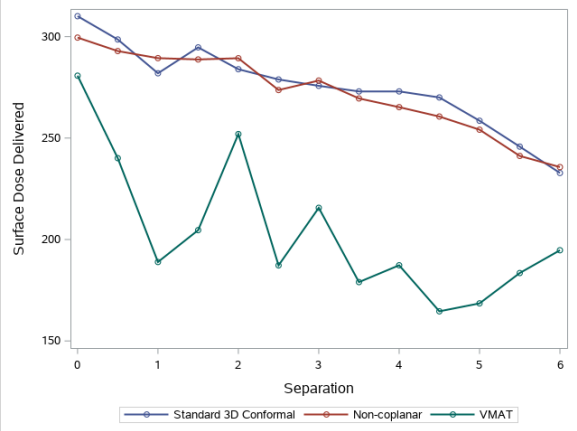


Fig. 6. *Surface dose as a function of at 0.5 cm increments*

As portrayed in existing studies, this data showed an inverse relationship between mean surface dose and separation. The data indicated an increase in surface dose as separation decreased. However, these tests only showed a significant difference with VMAT technique compared to the standard 3D technique. Again, the VMAT plan is determined to be the divergent plan in this work.

Considering the established data of prior studies, these results were substantial for exploring possible routes towards an avoidance of unnecessary increased skin dose. In this study, it was found that the surface dose caused by the bolus effect was not affected by a change in beam arrangement. This analysis also suggested that an increase in mean dose as a function of separation of breast from the prone breast device was not significant. Therefore, beam arrangement in 3D planning could not be proven effective as a solution towards the bolus effect. VMAT planning, however, showed means for an approach in avoiding the problem of increasing surface dose seen in prone breast radiation therapy.

Limitations and Improvements

An important discussion point that arose during these investigations involved the nature of the specific prone breast board. This Bionix immobilization device has the potential to differ than that of most other facilities. The model is outdated and no longer available commercially. Sleeker upgraded designs are now available for use with prone breast treatments. A noteworthy obstacle with the device was identifying a location for separation points. The space between the padding and breast was used for this data uptake, but it is observable in the isodose lines in the TPS that attenuation may occur more with the protruding carbon fiber component (fig. 7). Thus, separation points that involved this carbon fiber edge could have yielded different results with prone breast boards that are designed differently. This interaction is a prime example of that seen with the influence of attenuating external structures exposed in the works of Lau et al. [5]. It may be beneficial for future research to take this into consideration and may seek further answers using the TPS. For example, one can analyse the specific degree of attenuation in each plan by comparing calculations with and without the immobilization device.

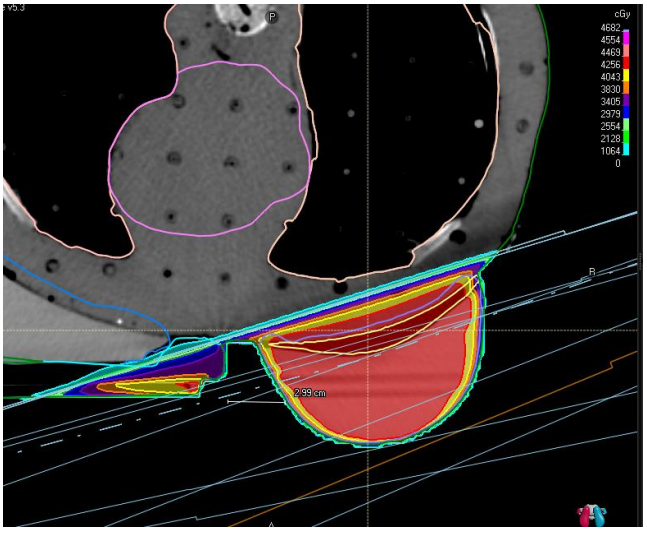


Fig. 7. *Isodose distribution shown on a cross-sectional image in Raystation10a.*

It is also worth discussing the characteristics of the fabricated breast phantom. The breast prosthesis alone may raise concern for its size and dimensions. In common practice, the prone breast positioning for breast treatments may be indicated for persons with considerably large and pendulous breasts. Whereas the targeted breast used in the study was designed to mimic the average sized breast. The results from this study may not determine if breast size contributes to the degree of observable bolus effect.

A possible improvement to this analysis of surface dose can involve incorporating pinpoint analysis in the TPS and comparing it to the measured in-vitro dose. This would be helpful in avoiding conditions where there may be suspicion of increased surface dose due to bolus effect, preventing the chance of acute dermatitis. This type of pre-emptive planning would require only a few more steps during the simulation process (acquiring multiple scans, wiring locations of concern, etc.) and more planning.

VI. CONCLUSION

Consideration should be taken when choosing a technique in prone breast treatment planning. This research showed that a non-conformal approach, as an alternative to standard 3D planning, does not show a difference in resulting surface dose. It is therefore recommended to explore other techniques in cases where concern for bolus effect exist. VMAT techniques pose significant effects on resulting surface doses compared to that of 3D techniques. This is important when there is an introduction of an immobilization device and possible changes in patient positioning involving this device.

Future studies should take many considerations into account when researching the incidence of increased surface dose caused by the bolus effect in prone breast radiation therapy. These factors include make and model of the prone breast device, the subjects involved, the location of measurement points, and the inclusion of TPS point dosing. Efforts in this area of study can ultimately reduce the incidence of acute skin side-effects, such as radiation dermatitis, involved in the treatment of a select subgroup of breast cancer patients.

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